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THE BULLETIN

of the

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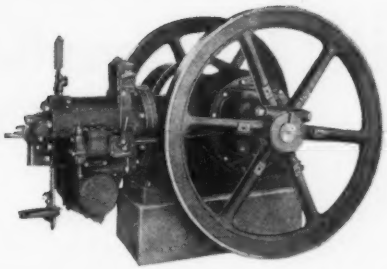

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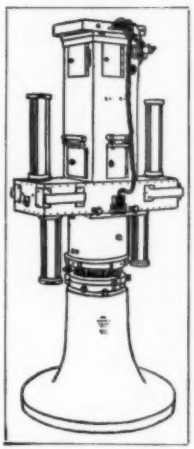

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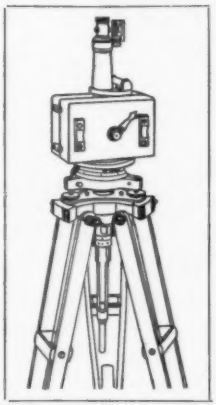

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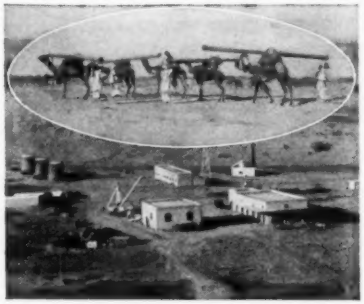

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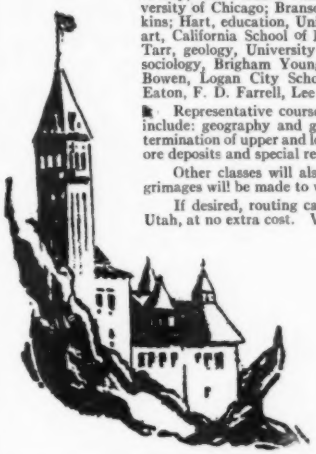

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Volume 12 Number 4

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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

APRIL 1928

ROCK PRESSURE[1]

WILLIAM B. HEROY[2]
New York, N. Y.

ABSTRACT

The term "rock pressure" is now commonly used in oil, gas, and underground water technology to refer to the pressure under which fluids are confined in rocks and takes no account of the cause or origin of the pressure, but simply of the fact of its existence. Geophysicists and isostasists are, however, using the term in the primitive and more correct sense of pressure exerted on underlying rocks by superimposed rocks, and it is suggested that in order to avoid confusion it is desirable to substitute for the term "rock pressure" as now used in oil, gas, and underground water technology the more appropriate term "reservoir pressure."

The various methods of determining reservoir pressure are discussed with special attention to the interpretation of the result secured. In the case of a closed-in well in which there is free gas and a column of oil, it is shown that a correct measurement of the pressure of the gas at the casing-head does not give the correct reservoir pressure. In the case where the reservoir pressure in oil and gas pools is due to hydrostatic pressure, it is shown that the reservoir pressures are progressively greater from the lower limit of the oil zone to the top of the oil zone than they would be in the same structure filled with water, and that the reservoir pressure throughout a gas pool is initially the same as the reservoir pressure at the point of contact of the gas with the adjoining liquid, and thus independent of the differences in elevation of the different parts of the gas reservoir.

Accurate and properly interpreted pressure determinations have value in the correlation of sands, in the determination of whether in a given region faults produce a seal or merely open channels of communication, and in the problems related to the depletion of oil pools and the encroachment of water. They are essential to oil

[1]Presented by title before the Association at the New York meeting, November 17, 1926. Manuscript received by the editor, January 13, 1928.

[2]Sinclair Exploration Company, 45 Nassau Street, New York City. The author wishes to acknowledge his indebtedness to Fay C. Brown, Arthur Knapp, Max A. Pishel, Sidney Powers, A. C. Veatch, and C. H. Wegemann for valuable constructive criticism of the manuscript.

operators in the management of their properties, so that the maximum production may be obtained from the oil deposits.

INTRODUCTION

For many years "rock pressure" has been in common use by petroleum geologists and engineers and, in fact, by oil-field workers generally. It is found in the professional literature and in the trade press of the industry since almost the beginning of oil-field development in the United States.

The writers who have used the term have been men of varied background, training, and experience. Their ideas as to what caused "rock pressure" have been greatly diversified and these differences have led to a wide variation in the significance which has attached to the expression. As most users of the term have made no direct explanations of the meaning which they attributed to it and the literature contains no formal definitions, readers are compelled to seek in the context the key to the thought behind each author's words.

In addition to "rock pressure" a variety of other terms and expressions are used by authors to describe conditions of pressure observed in oil and gas sands. Such terms as "artesian pressure," "hydraulic pressure," "gas pressure," "closed-in pressure," and "well pressure" are found in the literature, used either as direct equivalents of "rock pressure," or with special significance, and generally without definition. In the same article authors use "rock pressure" and some other similar term without distinction or discrimination. As the term "rock pressure" is that most widely used to designate the pressure under which fluids are confined in rocks, it has been taken as a short title for this paper. The use of the term "reservoir pressure" is suggested as a substitute which will have more significance to geologists.

Recent research has caused more frequent reference to, and observation of, "rock pressure." It is one of the important factors in the geophysics of oil fields. It will undoubtedly be much more rigorously investigated in the future.

ORIGINAL MEANING OF "ROCK PRESSURE"

Originally "rock pressure" was conceived to be the pressure exerted on any rock stratum by the overburden. Experience in coal and metal mining had shown that pressure exerted by the weight of the overlying rocks was the cause of the crushing in of workings, making necessary the timbering of mines. Many floors of mine workings,

composed of relatively soft rock, were upheaved as a result of "rock pressure." This pressure was observed to increase with depth along with the increase in weight of the overlying rocks.

Presumably these ideas and observations with regard to "rock pressure" were drawn upon to explain the phenomena observed in connection with the drilling of oil and gas wells. From the earliest days of oil development it was observed, when oil and gas sands were penetrated by the drill, that these fluids were as a rule under pressure and that, with increase in the depth of the wells, the pressure generally increased. As the oil and gas occurred in porous strata (called "sands" without regard to petrographic character) it was reasoned that the "sands" were under pressure because of the weight of the overlying rocks and that the fluid (gas or oil) contained in the sand was under similar pressure.

While the oil and gas were confineed in the stratum and no channels of escape existed it was considered that they would be under the same pressure as the rock stratum in which they occurred. Hence as oil and gas wells were drilled to greater depths the pressures would naturally be expected to increase, and this was found to be true by actual observation. To illustrate the point, the oil or gas sand was thought to be under pressure much as are the apples in a cider press, the fluids being squeezed out and escaping through the holes made by drilling into the sand.

It is doubtful if originally much thought was given to the physical side of the problem. In the light of our present concepts it would seem clear that the load of the overlying rock mass must be in one of two relations to the oil "sand." If the oil "sand" had sufficient strength to sustain the load without crushing or flowage, then the weight would be sustained by the sand itself and would not be transmitted to the fluids contained in its pore spaces. If the oil sand, on the other hand, were unconsolidated, or, if consolidated, were loaded beyond its capacity and had consequently yielded to the strain, then the load might be carried by the contained fluid and the entire rock mass above it would in effect be sustained by a sort of combined hydraulic and pneumatic cushion. Obviously the latter condition is the one which is consistent with the original idea of "rock pressure."

OVERBURDEN AS A CAUSE OF "ROCK PRESSURE"

Modern studies of the character of oil-bearing strata show that many oil "sands" are structurally so strong that they can and do sustain without crushing or movement the load imposed upon them. Con-

sequently such beds can be saturated with fluids without the fluids sustaining any of the load due to the weight of the overlying rocks. On the other hand there are many oil "sands" so unconsolidated that they readily flow, or have a low elastic limit. The fluids contained in such sands may partially or wholly sustain the weight of the overburden. Hence in such cases the weight of the overlying strata may be a direct cause of the pressure exhibited by the included fluids. Rogers[1] has briefly discussed "rock pressure" from this point of view as follows:

> Rock pressure is commonly believed to be the weight of the overlying column of rock which exerts a compressive effect on the beds beneath it. During the deposition of the sediments this undoubtedly leads to closer packing of the grains, but after a state of equilibrium has been reached the effect of further compression is a matter of speculation, unless the rocks concerned are deeply buried. A factor often overlooked in this connection is the tensile strength of the overlying rocks, which may conceivably be great enough to relieve a part of the pressure from a given point. As the weight of the strata is thus somewhat irregularly distributed, the rock pressure on a body of ground water must be irregular. Rock pressure is doubtless an important factor under some conditions, but its effect is generally an unknown quantity.

In the quotation, Rogers has used the term "rock pressure" in the sense of pressure exerted by the weight of overlying rock, and in strict conformity with what may be regarded as the original idea as to the cause of the occurrence of liquids under pressure in porous strata. Rogers' article contains no examples of "rock pressure" in the sense in which he has defined the term and I have found nowhere any specific instances of rock pressure directly related to this cause.

To what extent uncemented and unconsolidated oil sands will sustain load without transmitting it to the enclosed fluids is, as Rogers suggests, a speculative problem. If the oil sand were sufficiently consolidated to sustain the load there might still be much pore space available to be occupied by fluids. These fluids might still be under high pressure, but the pressure might be due to pressure-head and not to the weight of the overburden. If, however, the sand were not consolidated and the load were actually being carried by the liquid rather than by the sand itself, then extraction of the liquid would transfer the load to the sand which would tend to compact and thus occupy a smaller space vertically. The compacting of the sand would thus lead to a change in the level of the overlying rocks and cause subsidence.

Changes in level noted in the Goose Creek oil field[2] are considered

[1] G. Sherburne Rogers, "Chemical Relations of the Oil Field Waters in San Joaquin Valley, California," *U. S. Geol. Survey Bull. 653* (1917), p. 18.

[2] W. E. Pratt and D. W. Johnson, "Local Subsidence of the Goose Creek Oil Field," *Jour. Geol.*, Vol. 34 (Oct.-Nov., 1926), pp. 577-90.

to be due to the removal of the fluid content of the underlying oil sands. If the subsidence is due to this cause then it seems reasonable to assume that originally the load of overlying sediments was supported in the main by the contained fluids and not by the sands in which they occurred. The original "rock pressure" in the sand reservoirs of the Goose Creek oil field was 1,000 to 1,200 pounds per square inch. The reduction of this pressure by the removal of the fluids may have permitted the weight of the overlying rocks to be exerted against the oil sands. The resulting compression would be due to "rock pressure" in the sense in which the term is used by Rogers.

ARTESIAN CONDITIONS AS A CAUSE OF "ROCK PRESSURE"

Occurrences of oil and gas pressure directly due to the weight of the overlying rocks seem to be comparatively few and in any case difficult to establish. In comparison, illustrations of "rock pressure" attributable to artesian conditions are numerous and determined with mathematical exactness.

So far as the writer is aware the formulation of this relationship must be credited to I. C. White, who, as early as 1887, stated that artesian pressure was the cause of the compression of natural gas. Edward Orton, in several publications, not only discussed the causes of "rock pressure" but assembled exact data concerning the relations between "rock pressure" and artesian pressure, particularly with reference to the "Trenton limestone" in Ohio.[1] Of many examples given by him the following are interesting not only as demonstrating the cause of the pressure but also as illustrations of Orton's use of the term "rock pressure."[2]

> In Marion, Indiana, the gas rock was found at a depth of 78 feet below tide. To the 286 pounds of pressure due at tide level there must be added the weight of the 78 feet of salt water below the level named. The amount of the true pressure was 323 pounds. Visiting the field when the first well was completed I found that the gauge read 323 pounds. This fact was recorded before any theory whatever had been formed in regard to the cause of the rock pressure of gas. * * *
>
> In well No. 1, Upper Sandusky, gas was struck at 470 feet below tide, which would necessitate a rock pressure measured by a column of salt water of 1,075 feet in height. This would make the theoretical rock pressure of the gas 513 pounds. The actual pressure, as reported by Professor A. Bichardt, a careful and conscientious observer, was 515 pounds.

[1] *Geological Survey of Ohio* (Third Organization), *First Ann. Rept.* (1890), pp. 92-104.

[2] Edward Orton, "Petroleum and Natural Gas in New York," *N. Y. State Mus. Bull.*, Vol. 6, No. 30 (1899), p. 473.

Dr. Orton, in explanation of artesian conditions as a cause of "rock pressure," makes the following statement:

> When the stratum that holds the gas is porous and continuous, it must contain water, fresh or salt, in some portion of its extent. Whenever this water shows itself under artesian pressure it must of necessity exert on the oil or gas with which it is in contact the same force that causes the water itself to rise. The rock pressure of the gas can then be measured by the weight of the salt water column. Enough observations are on record to establish this deduction on a solid foundation. * * * This explanation of rock pressure imperiously requires certain conditions, viz., a continuous porous stratum rising somewhere to-day and thus acquiring artesian pressure.

This fundamental statement of principle in no way requires modification in the light of the more detailed knowledge of oil-field conditions now at our disposal. Very little addition to our knowledge of this subject was made by subsequent writers until after the development of the Mid-Continent fields, when interest in "rock pressure" was revived because of its practical bearing on oil recovery. Beal and Lewis[2] have re-stated this principle and its application as follows:

> In Oklahoma and in many other fields the "rock" pressure, or the closed pressure, of the oil and gas in an oil sand, is usually proportionate to the depth of the sand below the surface. As a general rule, the number of pounds of rock pressure per square inch that is to be expected previous to drilling into a new sand may be approximately estimated by the weight of a column of water of a height equal to the difference between the elevation of the lowest outcrop of the oil sand and that of the sand where penetrated by the drill.
>
> In the Cushing field the average rock pressures of the Layton, Wheeler and Bartlesville sands were in very close agreement with the theoretical pressure of a head of water measured vertically from the points where the sands were penetrated to the elevation of the supposed outcrop of the sands. Whatever may have been the original cause of the rock pressure in newly developed oil and gas fields this pressure shows a tendency to balance the hydrostatic pressure of the water in the same formation adjacent to the pool.
>
> In any district, especially in one like Oklahoma where the productive pools become progressively deeper as drilling proceeds westward, the ultimate production depends largely on the rock pressure, which in turn varies approximately with the depth of the pool.

In the Mid-Continent fields, the "elevation of the supposed outcrop of the sands" is, because of topographic conditions, not ordinarily very different from the elevation of the surface of the ground at the

[1]Edward Orton, "Petroleum and Natural Gas in New York," *N. Y. State Mus. Bull.*, Vol. 6, No. 30 (1899), p. 475.

[2]Carl H. Beal and J. O. Lewis, "Some Principles governing the Production of Oil Wells," *U. S. Bureau of Mines Bull. 194*, (1921), pp. 14-15.

well itself. The initial "rock pressure" has therefore been regarded by some as a direct function of the depth of the well, without considering that this in turn was due to hydrostatic pressure. In areas of greater topographic relief, such as the Appalachians and Rocky Mountains, the Mid-Continent "rule" does not everywhere apply.

Gardner has contributed a discussion of well pressures in Oklahoma in which he correlates the pressure of the wells with the weight of a hydrostatic column equivalent to the depth of the well:[1]

> It is an interesting fact that the closed pressure on the oil and gas wells in this portion of the Mid-Continent region closely approximates figures for the hydrostatic head of a column of water equal to the depth of the wells; or, in other words, 43.4 pounds per square inch for each hundred feet of depth. The well pressure is usually somewhat more or less than this figure, due probably to the fact that the water saturation is not complete, or that gas pressures for other reasons are usually strong.

Gardner supports these observations by several examples which show that the relationship stated to exist is essentially correct. Nothing in the data presented by him would indicate that the cause of the pressures described is to be attributed to other than artesian conditions.

ROCK PRESSURE IN CLOSED LENSES

Several writers have pointed out that oil, gas, and water in many places exist under pressure in closed lenses of "sand" which have local distribution only and which do not have sufficient regional extent to admit of artesian conditions being established in them. These "sands" do not reach the surface and they are closed off from other horizons by intervening and impermeable strata. Having no source of surface infeed, the "rock pressure" observed in them cannot apparently be attributed to the weight of a column of water reaching somewhere to the surface. Gravity does not, therefore, appear to be the primary factor in the creation of the condition of "rock pressure" in the sand. The fluids which such sands may contain may show lower or higher pressures than would be expected from artesian conditions. Orton noted an instance of a pressure of 1,540 pounds from a well only 2,370 feet in depth which he was unable to explain as due to artesian head. Rogers[2] was aware of some of the problems arising in this connection:

> Gas pressure must also be taken into account in regions in which gas is contained in the rocks. In general the gas pressure in any sand is less than

[1] James H. Gardner, "The Mid-Continent Oil Fields," *Bull. Geol. Soc. Amer.*, Vol. XXVIII (1916), pp. 700-02.

[2] G. Shelburne Rogers, "Chemical Relations of the Oil Field Waters in San Joaquin Valley, California," *U. S. Geol. Survey Bull. 653*, (1917), p. 18-19.

the weight of an overlying column of water, but there are many sands in which it is considerably greater and in which, therefore, its influence must be considered. If a sealed sand lens is filled partly with water and partly with gas under pressure, the water may flow out under great apparent head when the sand is tapped. When the gas has expanded somewhat, the apparent head of water decreases, and some, though not all, of the decrease in the head of oil-field waters is doubtless due to diminishing gas pressure. Some puzzling differences in the head of these waters may also be ascribed to gas pressure, the effect of which cannot be overlooked, although its ultimate cause has never been satisfactorily determined.

These illustrations of "rock pressure" in isolated "sands," where water, oil, and gas are held under pressure within a limited zone, may be compared to the conditions existing in a chemical fire extinguisher where the fluid and gases are contained within a metallic shell. In fact the term "shell pressure" has been used to describe the condition of "rock pressure" existing in such an isolated lens or zone.

The origin of these exceptional pressures in isolated sands is a matter of speculation. But little is known about the factors which may have contributed to the building up of these pressures and there have been no critical contributions to the problem. Mills, in a personal communication, suggests geochemical origin as a probable cause, comparing it to the pressure of fermentation in sealed bottles, the pressure being confined by the capillary resistance to movement through the surrounding strata.

Perhaps this part of the subject may as well be left in the position stated by Mills and Wells as follows:[1]

> It seems probable that hydrostatic pressure, weight of superincumbent strata, rock movements, deep-seated thermal conditions, the long-continued formation of natural gases, and the resistance to fluid movements through the strata all enter into the causes for "rock pressure."

DEFINITION OF "ROCK PRESSURE"

From the citations which have been made it is clear that the term "rock pressure" is used in petroleum literature to describe an observed fact that fluids exist under pressure in the rock strata. While some authors have used the term in a more restrictive sense, to denote pressure derived from a particular cause, or ascribed to a particular condition, the present-day usage takes no account of the cause or origin of the pressure but simply of the fact of its existence. It is consistent,

[1] R. V. A. Mills and R. C. Wells, "The Evaporation and Concentration of Waters associated with Petroleum and Natural Gas," *U. S. Geol. Survey Bull. No. 693* (1919), p. 29.

therefore, with general oil and gas practice to define the term "*rock pressure*" as that pressure under which fluids are confined in rocks.

Geophysicists and isostasists, however, have used, and are using, the term "rock pressure" in the primitive and more correct sense of the pressure exerted on underlying rocks by superincumbent strata. In order to avoid confusion it is desirable to substitute for the term "rock pressure" as now used in oil, gas, and underground water technology, the more appropriate term "reservoir pressure."

The three fluids which exist in the rock strata are commonly water, oil, and gas. A "dry sand" is one that, upon being tapped, yields no liquids and no gas above atmospheric pressure. A sand which contains gas under pressure is commonly spoken of as showing "gas pressure." If, however, the sand contains only water, the pressure under which it occurs is termed "hydrostatic pressure." And if, as is not at all exceptional, the hydrostatic pressure is due to the existence in the sand of artesian conditions, it is commonly spoken of as "artesian pressure."

In contrast with the term "gas pressure" we may use the term "liquid pressure" to refer to the pressure of either oil or water, or both. We have no term to describe the pressure under which oil may occur as distinguished from that of water. These relations may be shown diagrammatically as follows:

- "Rock pressure" or "Reservoir pressure"
  - Gas pressure
  - Liquid pressure
    - Pressure of oil
    - Hydrostatic pressure
      - Artesian pressure

Pressure is commonly measured in pounds per square inch. The metric unit, kilograms per square centimeter, is not used in American petroleum practice.

DETERMINATION OF RESERVOIR PRESSURE

The amount of reservoir pressure is seldom, if ever, directly determined. Our present conceptions of pressure conditions in underground reservoirs are almost entirely deductions from observations made, not in the reservoir itself, but at the surface. The only method now available for obtaining information concerning conditions in such reservoirs is to penetrate them by means of wells drilled from the surface. The fluids held under pressure in the reservoir force themselves

into the well and toward the surface. If the reservoir, at the point penetrated by the well, contains only gas under pressure, the gas will be released from the reservoir, will fill the well shaft, and will escape under pressure at the surface. If the reservoir contains liquids, these may either rise in the well shaft toward the surface or, if the pressure is sufficiently great, may be forced to the surface and flow from the well.

Measurements may be taken showing the pressure exerted at the mouth of the well by the fluids in the well or showing the height to which the liquids rise in the well. It is clear, however, that the conditions of pressure at the well mouth may be very different from those at the bottom of the bore where the well enters the reservoir or "sand." The conditions of pressure in the reservoir at the point where it is penetrated by a well may also be different from those in other portions of the reservoir at a distance from the point where it is tapped and where the conditions of pressure may be comparatively undisturbed.

MEASUREMENT OF WELL PRESSURE

The pressure at the mouth of a well exerted by fluids in the well shaft is usually determined by attaching a pressure gauge to the well casing. The pressure so measured is commonly called "well pressure" or, more specifically, the "casing-head pressure." This pressure is determined by completely shutting in the well for a sufficient time for the pressure, as indicated on the gauge, to reach a maximum and to become approximately constant. Consequently well pressure is, for this reason, also called "closed-in pressure" or "gauge pressure." All of these terms refer to conditions observed at the mouth of the well. They are not, therefore, equivalent to "reservoir pressure," which, as appears from the previous discussion, would be used with reference to conditions existing in the fluid reservoir itself. It is not uncommon, however, to find that measurements of well pressure are referred to as measurements of "rock pressure" on the assumption that the measurements at the surface are indicative of conditions in the reservoir. As will be pointed out later, however, this reasoning is inexact and often leads to serious errors in interpretation.

Measurements of well pressure are in themselves subject to certain inaccuracies. Obviously the value of such a measurement depends on the accuracy of the instrument used, upon its proper calibration, and on the personal equation of the observer. High-pressure gauges easily lose their accuracy under field conditions and frequent comparison and standardization are essential if results which have scientific value are

to be obtained. Even with close calibration, errors of 1 per cent of the scale reading are considered allowable, so that on well pressures of 1,000 pounds or more the reading on a carefully calibrated gauge may not be accurate within ten or fifteen pounds. With ordinary field use and infrequent calibration, instrumental and observational errors may considerably exceed these figures.

Errors of handling, observation, and recording are not infrequent. Haste in reading may result in the well pressure not being permitted to reach an approximate maximum. Extreme cold may affect the operation of the gauge or cause moisture to freeze in the casing head, so as to affect the reading. The fittings at the well head or the gauge connections may not be absolutely tight, permitting some gas or liquid to escape, thus causing the pressure reading to be lower than the pressure actually is. The opening of a valve too rapidly, thus bringing pressure on a gauge too suddenly, has been known to disturb its calibration and destroy its accuracy. Simple mistakes in recording are not unknown. Consequently, we are faced with the fact that reported measurements of well pressure contain inaccuracies which may interfere with correlation and interpretation of results.

When a gas well flowing from an otherwise dry sand is first closed in, the gauge reading will not indicate the full gas pressure. For some time thereafter the pressure will gradually increase toward a maximum and the gauge will then show the full casing-head pressure. Moreover a well which has been closed in for some time will show minor fluctuations in pressure, due to any change of load at the surface, such as barometric variation and perhaps to changing conditions in the sand itself. These minor variations are ordinarily too slight to have an important bearing on the studies of underground conditions. Pressure at the mouth of the well may be due to liquids as well as to gas, and will be similarly indicated by the gauge.

MEASUREMENT OF WELL HEAD

When gas is absent and the column of liquid in the well does not reach the surface, and, in consequence, exerts no pressure at the casing head, the conditions of pressure in the "sand" may be determined by measuring the height to which the liquids rise in the well casing. Where the surface of the liquid in the casing is at some distance below the mouth of the well, its elevation is determined by the use of a steel line, or tape and float. The depth of the well being measured by the same means, the height to which the fluid rises above the "sand" is easily computed.

Where the pressure of fluid in a well is sufficient to flow the fluid over the casing, the total head may be determined by attaching a small vertical pipe to the casing head, and permitting the fluid to rise in this pipe to such an elevation as the pressure may require. Head above the casing may thus be measured and the total head computed by adding this amount to the total depth to the sand. This method can be used only where the pressure is moderate and not sufficient to force the fluid higher than the top of the derrick.

MEASUREMENT OF PRESSURE WITHIN THE WELL

The desire for more accurate knowledge of conditions of pressure in oil and gas wells has recently led to the development of methods of investigation along new lines.

The first method, which is used in California,[1] is applicable to wells producing oil, gas, and water, which have been equipped with casing and tubing. Gas is forced into the tubing and also between the tubing and the casing until the fluids in the well have been driven downward to the bottom of the tubing and the pressures balanced at that point. When the fluid level has reached the bottom of the tubing, the gas pressure is read. This pressure plus the weight in pounds per square inch of the column of fluid extending from the bottom of the tubing down to the reservoir gives the rock pressure.

A somewhat similar method is to pump gas into the casing, pressing the fluids in the well downward until they have been forced completely out of the well into the reservoir. The gas pressure required to produce this result is the corresponding reservoir pressure. While the fluid is being forced from the well into the reservoir, the gauge reading will gradually increase until the bore of the well has been entirely cleared and the gas passes directly into the reservoir. Beyond this point no further increase in pressure will be indicated and the reading will then indicate the reservoir pressure.

A "pressure bomb" has also been devised[2] for determining the gas or fluid pressure at any point in a well. It consists of a short piece of casing closed at one end and fitted with a steel plate which can be screwed in to close the other end. In this plate a hole is drilled into which a pressure gauge is screwed. When the steel plate is fitted into position the gauge is on the inside of the bomb in such a position that it is protected from injury, but is affected by the pressure communi-

[1]Personal communication from A. C. Rubel.

[2]Personal communication from C. H. Wegemann.

cated through the hole in the steel plate. The pointer on the pressure gauge is so bent as to touch lightly the glass covering the face of the gauge, which is smoked with lamp black. The bomb is then lowered in the well to the producing horizon and the well closed in so as to permit the pressure to build up to a maximum. The maximum pressure is recorded on the lamp black by the scratching of the hand of the gauge.

Before proceeding further with the discussion it is desirable to define some additional terms. Whereas the unit of pressure measurement is pounds per square inch, head is measured in feet vertically. The *rise* of a liquid in a well is the distance measured from the elevation of the reservoir from which it flows to the surface of the liquid. The *head* is the vertical distance from the surface of the fluid to some plane of reference. If the fluid rises above the mouth of the well, head may be measured with reference to the elevation of the casing head, of the derrick floor, of the ground surface, of the sand, of the bottom of the well, or of sea-level. The amount of head will thus vary with the datum selected. "Head" is a contraction of "*pressure head*" or "*static head*," of which the latter term is perhaps to be preferred as more precise and less likely to be confused in meaning with others. "*Hydrostatic head*" has the same meaning as "static head," except that it indicates that the liquid measured is water. "*Well head*" simply means the static head of fluids in a well as contrasted with such measurements made in pipelines, etc.

INTERPRETATION OF MEASUREMENTS OF PRESSURE AND HEAD

Measurements of pressure and of head cannot always be taken as indicators of reservoir pressure, without analysis and interpretation.

Before proceeding with the consideration of the various conditions which arise, an additional source of inaccuracy must be pointed out. Measurements of pressure or head are subject to error because fluid or gas may escape from the well between the reservoir and the casing head, on account of improper casing or because the well is not completely cased. There may, for example, be dry sands above or below the reservoir,—sands into which fluids may escape if not confined to the well bore by tight casing. The well may also penetrate other sands which have for some reason a lower reservoir pressure than the principal sand and into which fluids may similarly be forced by the difference in pressure. Losses of pressure under these conditions are seldom, if ever, detected.

The most important factor in the interpretation of measurements of pressure and head is the nature of the fluid which the reservoir con-

tains at the point where it is penetrated by the well and which, in consequence, enters the well shaft. Wells drilled in search for oil and gas may encounter in the reservoir gas entirely free from oil or water. They may find it saturated with water, either fresh or salt, without any admixture of oil or gas. They commonly find gas in combination with oil; they may find water associated with oil and little or no gas; and wells are not exceptional which flow oil with little, if any, accompanying gas or water. These varying conditions complicate the analysis of the problem. For purposes of discussion these various combinations may be grouped in the following four classes: (1) the reservoir yields only gas, (2) the reservoir yields only one liquid, (3) the reservoir yields two liquids, and (4) the reservoir yields a liquid and gas.

The conditions of pressure in each of these four conditions will be described in turn.

1. *Reservoir yielding only gas.*—Gases are perfectly elastic and transmit pressure equally in all directions. Consequently in the case where a well penetrates a gas sand the pressure indicated at the casing head will, in the absence of leakage, be the same as the pressure in the sand itself and will consequently be identical with the reservoir pressure.

2. *Reservoir yielding only one liquid.*—In the case of a well containing a single liquid under pressure, not mixed with gas, the casing head pressure does not indicate the reservoir pressure. If the liquid does not fill the well the reservoir pressure is the weight in pounds of a column of the liquid with an area of one square inch extending from the reservoir to the surface of the liquid. If this height in feet is known by measurement, the reservoir pressure in pounds is the product of the static head in feet, the specific gravity of the liquid, and the factor 0.434 (the weight in pounds of a column of pure water one inch square and one foot in height). If the liquid overflows the well casing, the head used in this calculation must be increased by the distance that the liquid will rise above the casing head. If the well pressure is determined by a gauge, it is evident that the pressure observed is only that exerted by the liquid at the casing head and that the reservoir pressure is equal to the sum of such gauge reading and of the unit weight of the column of fluid in the well. If, for example, water with a specific gravity of 1.01 were found in a sand at a depth of 1,000 feet and not only filled the casing but exerted a pressure of 100 pounds at the casing head, the reservoir pressure would be 100 pounds plus the product of $1{,}000 \times 1.01 \times 0.434 = 538.34$ pounds.

3. *Reservoir yielding two liquids.*—If the column of liquid in a well is composed of two liquids, water and oil (gas being absent), the

problem is somewhat more complicated. Oil, as a rule being lighter, will occupy the upper part of the casing with water below it. To determine the weight of the column of liquid, it is necessary to determine separately the head of water and that of oil. The elevation of the oil surface is determined as though only one liquid were present. The elevation of the water-oil contact is determined by making successive tries with the bailer until it is brought up with some water content. The reservoir pressure will then be the sum of the weight of the water column and that of the oil column, proper specific gravities being used in each calculation. This condition of mixed fluids is more likely to occur in wells in which the fluid level does not reach the top of the casing. Where the fluid flows over the top of the casing and is a mixture of oil and water, an approximate result can be reached by weighting the specific gravity proportionally to the amounts of water and oil being produced.

4. Reservoir yielding a liquid and gas.—One of the most common conditions is for a well to produce both oil and gas under pressure. Mixtures of water and gas alone are exceptional. The production of water along with oil and gas is very common. This latter condition is ordinarily too complex for mathematical analysis, but the more common mixture of gas with oil will be considered.

In most oil wells the oil contains more or less absorbed natural gas. The absorption coefficient[1] of natural gas in crude petroleum varies with the characteristics of the particular petroleum and of the particular natural gas which is absorbed in it. Each combination of oil and gas will, therefore, have its own particular coefficient, which may be determined by physical investigation. Some work has been done by the Bureau of Mines[2] which bears upon this determination, although the results are stated in a different form. If, under pressure, natural gas is absorbed in a crude petroleum, the amount of gas which will be absorbed will, theoretically, increase proportionately to the increase in pressure. Natural gas is, however, not a simple substance, but as a rule a mixture of several gaseous hydrocarbons, each having its own absorption coefficient with respect to any given petroleum. Moreover, each has a different critical temperature and pressure. Whenever, therefore, with exercise of pressure, the stage is reached at which one

[1]The absorption coefficient of a gas in a liquid is the number of units of volume of a gas which can be absorbed by unit volume of the liquid, determined at 15° C. and at the atmospheric pressure.

[2]D. B. Dow and C. E. Ristle, "Absorption of Natural Gas and Air in Crude Petroleum," *Mining & Metallurgy*, July, 1924, pp. 336-7.

of the hydrocarbons constituting the natural gas will liquefy, it will cease to act as a gas, but will become a liquid hydrocarbon and mix with the petroleum in which it was absorbed. After this stage is reached this particular hydrocarbon would cease to obey gas laws. As the critical pressure of each constituent gas is reached, each will in turn liquefy and merge with the petroleum. Certain hydrocarbons, which at ordinary temperatures and pressures are present in natural gas, may, under conditions of high pressure, be present in petroleum in two conditions—either liquefied and forming an integral part of the fluid, or absorbed and acting as a gas. This statement is true only of relatively wet hydrocarbons, for methane, which is the most important constituent of natural gas, has a critical temperature of $-95.5°$ C.[1] and hence does not liquefy at ordinary temperatures or under any conditions which may normally exist in underground oil deposits.

Under the high pressures that exist in many oil fields, the volume of natural gas which may be absorbed in the oil becomes very large. At the not uncommon pressure of 1,000 pounds per square inch it is probable that one barrel of oil will absorb 200 cubic feet of natural gas. In some oil fields natural gas is present in excess of the amount which the petroleum present can absorb under the existing pressures. This excess gas will collect in the higher part of the structure as free gas, sharply separated vertically from the liquid hydrocarbons which form the petroleum.

When a well penetrates a sand containing petroleum charged with natural gas under high pressure, the immediate effect is to release part of this pressure, much as charged water is released from a soda syphon. As the oil and the accompanying absorbed gas are forced by the reservoir pressure from the sand into the lower part of the well and rise through the casing toward the well head, the pressure on the fluid diminishes as it rises, permitting the evolution of part of the absorbed gas. As the gas, with the release of pressure, is freed from its absorbed condition it forms bubbles in the rising column of fluid, which will expand as the pressure is further reduced by further rise in the well shaft. As the mixed column of gas and oil rises to the casing head, the gas will thus continually expand in volume with increase in elevation above the sand and consequent reduction in pressure. This condition will exist while the column of mixed oil and gas is flowing upward through the casing.

If such a well is closed at the casing head, a point is soon reached where approximate equilibrium is established in the well. The reservoir

[1] *Smithsonian Physical Tables*, 7th Edition, 1923, p. 212, quoting Dewar Ch. News, 84, 1901.

pressure in the sand will then remain approximately constant and the oil at the point where the well enters the sand will be saturated with gas to a degree which depends upon the amount of reservoir pressure, the absorption coefficient, and the quantity of gas present. With increase of elevation in the well the static head of the oil column and the pressure on the oil in pounds per square inch correspondingly decreases and the amount of gas which a given amount of oil will hold in solution proportionately diminishes. The excess gas thus released from solution collects at the top of the casing where it is held under pressure, creating a column of free gas above the oil.

The gas so confined in the upper part of the casing will exert pressure against the casing head and, being completely elastic, will exert the same pressure downward against the column of oil beneath it. In turn, the oil forced upward by reservoir pressure will exert the same pressure against the free gas. In this case the pressure of the gas against the casing head, as shown by a gauge, is not the true reservoir pressure. The actual reservoir pressure is the sum of the casing-head pressure and of the pressure exerted by the weight of the column of fluid in the lower part of the casing. It will necessarily always be in excess of the observed casing-head pressure.

It has been common practice in the industry to measure the well pressure of wells yielding both oil and gas and to refer to this measurement as "rock pressure." Such pressure measurements clearly do not show the true reservoir pressure. Casing-head pressure observed under these conditions is not a quantity which can be compared with the casing-head pressure of a well yielding only gas, which, as already shown, is the same as the reservoir pressure. Neither is it equivalent to the unit weight of the water column which the reservoir pressure will support in those portions of the sand yielding only water. It does not by itself afford a basis for calculating the true reservoir pressure.

To ascertain from the casing-head pressure the actual reservoir pressure in a well, the height of the column of fluid below the gas must also be determined. It should not be difficult to devise an apparatus for making such a measurement, but it is apparently quite as simple to determine the actual reservoir pressure by the use of the "pressure bands."

Up to the present time there have been comparatively few accurate measurements of reservoir pressure in wells producing both oil and gas. Measurements which are commonly given in the literature are misleading in that they state lower reservoir pressures than actually exist.

Failure to interpret them correctly and to give them their proper weight has led to confusion and efforts to correlate such readings with observations of gas pressure and hydrostatic head in the same field have naturally been unsuccessful.

In the accompanying diagram (Fig. 1) the four conditions which have just been described are illustrated.

CORRELATION OF MEASUREMENTS OF RESERVOIR PRESSURE

If a sand containing water under artesian pressure is tapped, the water will rise to an elevation corresponding to the amount of this pressure, which is commonly termed "hydrostatic level." If the sand is continuous, if there is no outflow or leakage and the conditions of porosity are such that pressure is transmitted freely from one portion of the sand to another, a condition of equilibrium will exist, so that theoretically, at least, the hydrostatic level will be at the same elevation for all points throughout the extent of the sand. Actually, such ideal conditions seldom, if ever, exist. Variations in porosity of the sand, unequal distribution of inflow, frictional resistance to free movement, natural leakages, and irregularity in the distribution of the wells by which the flow is developed, all tend to create irregularities in the hydrostatic level. In two adjacent wells tapping the same stratum carrying water under pressure, it would nevertheless be expected that the water would rise to essentially the same height. This elevation would clearly not be dependent upon the elevation of the sand at the points where it was penetrated, nor on the depths of the wells, nor on the elevations of the ground at the wells. If, however, the stratum contained under pressure not only water, but oil and gas, the situation would be somewhat modified. If, for example, an oil well were to offset a water well in the same sand, it is clear that, oil being commonly lighter than water, the oil would rise higher than the water—that is, the static level of the oil would have a higher elevation than that of the water. But, if proper allowance were made for the lighter specific gravity of the oil, it would be expected that the pressure head of the water and of the oil would show essential agreement.

Similarly, in the case of a gas well originating in the same stratum, the gas pressure at the mouth of the well would be, as has already been shown, the same as the reservoir pressure in the sand. This pressure would support a column of water of such height that its top would reach the level to which water would rise in a well reaching water in the same sand.

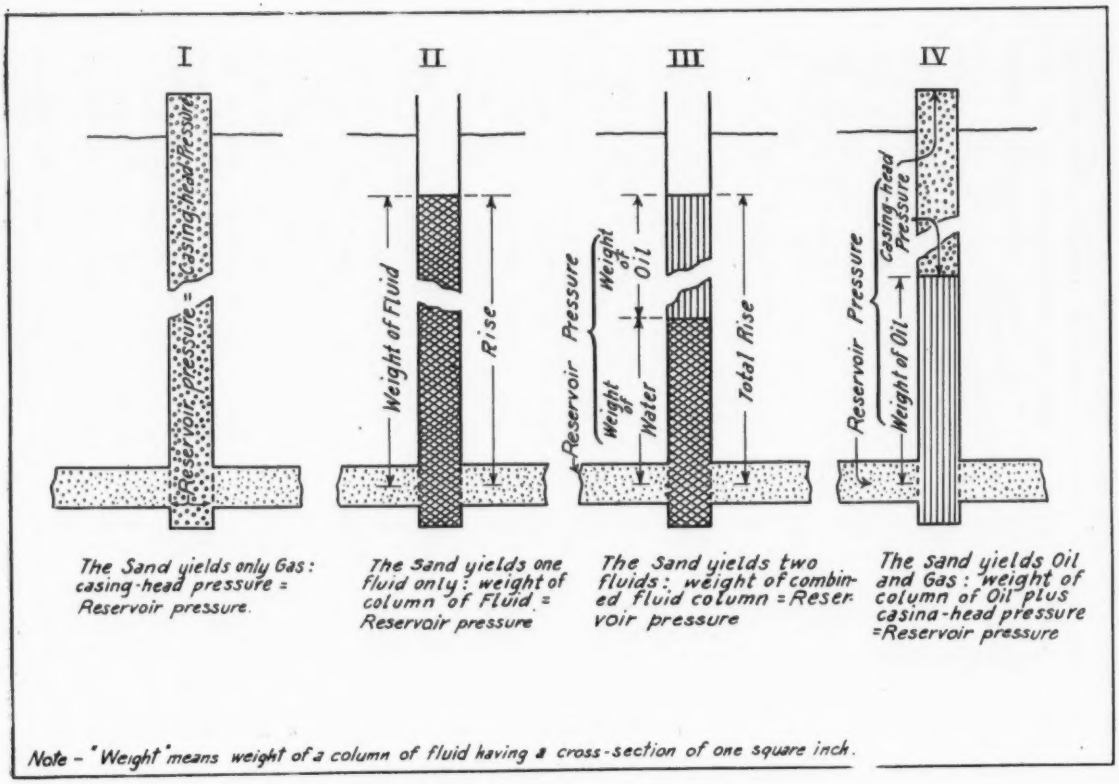
I
II
III
IV
Casing-head pressure =
Reservoir pressure
Weight of Fluid
Rise
Reservoir Pressure
Weight of Oil
Weight of Water
Total Rise
Reservoir Pressure
Casing-head Pressure
Weight of Oil
The Sand yields only Gas: casing-head pressure = Reservoir pressure.
The Sand yields one fluid only: weight of column of Fluid = Reservoir pressure
The Sand yields two fluids: weight of combined fluid column = Reservoir pressure
The Sand yields Oil and Gas: weight of column of Oil plus casina-head pressure =Reservoir pressure
Note - "Weight" means weight of a column of fluid having a cross-section of one square inch.

FIG. 1

When a sand contains all three fluids, it is evident that the hydrostatic level would actually extend only over that part of the sand containing water. However, in the areas containing oil and gas there exists an equivalent level to which the amount of rock pressure existing in the oil and gas areas would cause a column of pure water to rise. This level may be termed the "*equivalent hydrostatic level.*" All wells tapping in the same reservoir bed, whether water, oil, or gas, should, therefore, have approximately the same equivalent hydrostatic level, assuming the same source of pressure and essential freedom of transmission of pressure throughout the bed. A porous stratum, or reservoir, in which there is a common source of artesian pressure and in which pressure is transmitted with essential freedom from one part of the stratum to another, and the wells which communicate with it may be said to belong to the same "*pressure system.*"

If it were possible to determine for a given reservoir the equivalent hydrostatic level corresponding to each point in it, these would together form an imaginary surface. This has been termed in connection with areas yielding artesian water a "piezometric surface." With absolutely static conditions of pressure in the reservoir, this surface would be a plane. Under actual existing conditions it is more likely to be a gently sloping, curved, or warped surface. A vertical cross-section of such a surface in any direction would give a profile which may be called an "*equivalent hydrostatic profile,*" or, for convenience, the "*static profile*" of the liquifer.

It should be emphasized that neither a piezometric surface nor a static profile is permanent in form. Each is constantly being modified as changes in pressure occur in the reservoir to which they correspond. While, prior to development, conditions of pressure may have been essentially stable throughout a field, the first well to reach the reservoir will disturb this equilibrium. As the liquifer is tapped by additional wells, changes in pressure will occur more rapidly, for, on account of the frictional resistance of the sand to the movement of fluids, adjustment of pressure can not as a rule keep pace with development. Consequently, in developed fields (and it is on such fields that our observations must be based) a condition of pressure equilibrium will seldom be found. The original conditions of pressure which existed in the field can not be determined by observation but must be reconstructed from data subsequently obtained.

With these explanations of the principles involved, the problem of correlating measurements of well pressure and rock pressure so as to

determine the characteristics of the pressure system existing in a given reservoir may be studied.

CORRELATIONS UNDER CONDITIONS OF ARTESIAN PRESSURE

Let us assume an undeveloped oil and gas pool of anticlinal structure in which the oil and gas are retained in the upper part of the structure by the upward pressure of the surrounding water—that is, by artesian pressure. Gravitational separation of the three fluids will occur: water below; oil, with absorbed natural gas, in an intermediate position; and free gas on the crest of the structure. These relations are shown diagrammatically in the accompanying illustration (Fig. 2), which is a hypothetical cross-section of a structure of the type described. This cross-section may be considered an ideal static profile across such a structure, drawn without regard to local irregularities caused by varying porosity and variations in sedimentation.

For convenience of reference and analysis it is desirable to select a datum to which structural elevations, static heads and ground elevations may all be referred,—sea-level, or some elevation bearing a convenient relation to it. In the diagram the following elevations above datum are assumed: water-oil contact, 500 feet; oil-gas contact, 1,000 feet; equivalent hydrostatic level, 2,500 feet; ground elevation, 3,000 feet.

A well, "*A*," is assumed to be drilled into the water-bearing portion of the reservoir, to have a ground elevation of 3,000 feet, and to reach the sand at a depth of 2,700 feet. On measurement, water is found to rise in the well to a point 500 feet below the gound, or 2,500 feet above datum. The static level is thus fixed at 2,500 feet (taking the specific gravity of the water as 1.00; under field conditions it may vary considerably). The pressure head of the column of water 2,200 feet high is computed (2,200 × 0.434) to be 935 pounds, which determines the reservoir pressure at the point where the well intersects the sand.

The reservoir pressure is not uniform throughout the structure but will vary with the relation to the datum of any particular point on the sand. If the sand contained only water the pressure would uniformly decrease with increased elevation in the structure, as shown by the second column of figures on the left of the section. These figures apply, however, only to the portion of the structure filled with water. In the part containing oil and gas other factors enter into the calculation.

For the part containing oil the reservoir pressure would actually be greater than if the whole layer was filled with water. This apparently

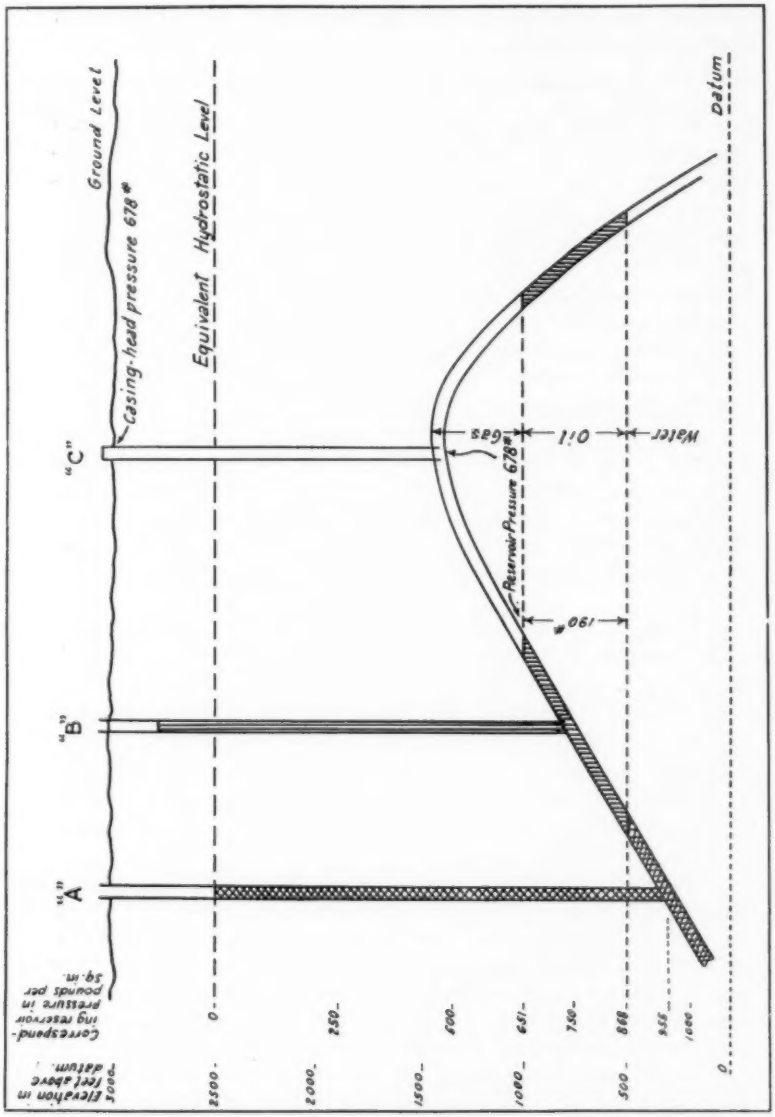
Ground Level
Casing-head pressure 678#
Equivalent Hydrostatic Level
Datum
"C"
"B"
"A"
Gas
Oil
Water
Return Pressure 678#
190#
Elevation in feet above datum.
Corresponding reservoir pressure in pounds per sq. in.
2500
2000
1500
1000
500
0
250
500
750
1000
1250
1600
0

FIG. 2

paradoxical condition is due to the fact that owing to the greater weight of the water, as compared with the oil, more of the artesian column exerts an effective pressure on the top of the structure (or any part containing oil) when the fluid-bearing layer of the structure is partially filled with oil than when filled entirely with water. This may be illustrated by the accompanying diagram (Fig. 3).

If the porous layer *ABC* is entirely filled with water, the rock pressure at *B* is the effective weight of the column of water *CB*, which we may take in this illustration as 1,200 pounds. The reservoir pressure at *A* would then be the pressure at *B* less the weight of the 600-foot column of water *AB*. As this column of water would give a pressure per square inch of 600 × 0.434, or 260.4 pounds, the reservoir pressure at *A*, when the layer is filled with water, would be 1,200 less 260.4, or 931.6 pounds.

If the fluid in *AB* is composed of 100 feet of water and 500 feet of oil of 30° gravity, the pressure at *A* would likewise be the effective pressure at *B* of 1,200 pounds less the combined weight per square inch of the fluids in *AB*. Oil of 30° Bé. has a specific gravity of 0.875 and would therefore have for each foot the water value of 0.434 pounds × 0.875, or 0.37975. The 500 feet of oil would then give a pressure to the square inch of 500 × 0.37975, or 190 pounds. One hundred feet of water would give 100 × 0.434, or 43.4 pounds, and the total weight of this combined column of oil and water would be 190 plus 43.4, or 233.4 pounds per square inch. The reservoir pressure at point *B* would then be 1,200 pounds less 233.4, or 966.6 pounds. Thus with exactly the same artesian pressure at *B* the reservoir pressure at *A* would be 35 pounds greater if the structure contained oil (with an oil-water contact 500 feet below the point *A*) than if it were completely filled with the heavier liquid, water.

Returning now to Figure 2, at the assumed water-oil contact (500 feet above datum) the reservoir pressure is 868 pounds. The water is exerting a peripheral pressure against the margin of the oil corresponding to the reservoir pressure at that elevation. But the oil extends vertically above this line 500 feet. Assuming a gravity of 30° Bé. (specific gravity 0.875), the 500 feet of oil will not have the same weight as a column of water of the same height, which would be 217 pounds, but 0.875 of that amount, or 190 pounds. For each foot of increase in structural elevation the loss in reservoir pressure would be for water 0.434 pounds. For 30° oil it would be 0.875 × 0.434, or 0.37975.

Let us next assume in Figure 2 a well, "*B*," drilled to the oil sand at a point 800 feet above datum and thus entering the sand at a struc-

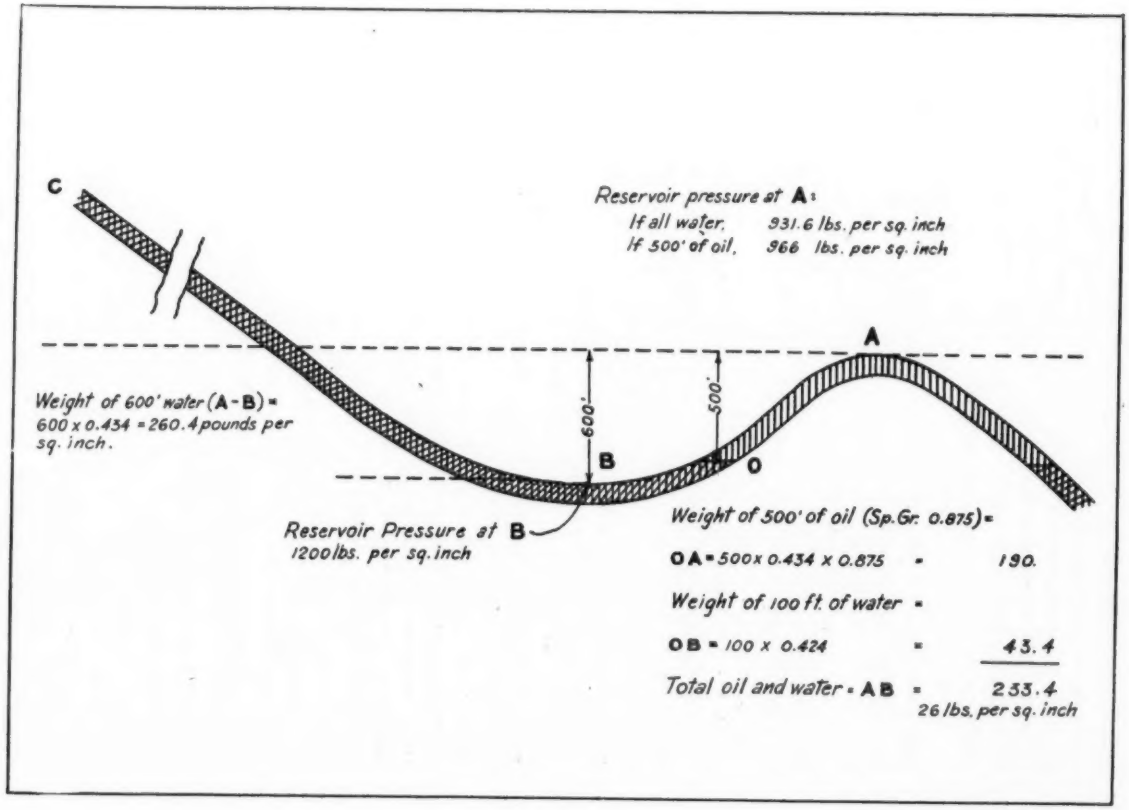
C
Reservoir pressure at A:
If all water, 931.6 lbs. per sq. inch
If 500' of oil, 966 lbs. per sq. inch
A
Weight of 600' water (A-B) =
600 x 0.434 = 260.4 pounds per sq. inch.
600'
500'
B
O
Reservoir Pressure at B
1200 lbs. per sq. inch
Weight of 500' of oil (Sp.Gr. 0.875) =
OA = 500 x 0.434 x 0.875 = 190.
Weight of 100 ft. of water =
OB = 100 x 0.424 = 43.4
Total oil and water = AB = 233.4
26 lbs. per sq. inch

FIG. 3

tural elevation 200 feet above the water-oil contact. The pressure of 868 pounds at the oil-water contact would sustain a column of water 2,000 feet high and a column of 30° oil 2,285 feet high. Hence, ignoring questions related to the effect of dissolved gases, the oil would rise to an elevation of 2,785 feet above datum, or 285 feet above the static level.

As shown, the reservoir pressure at the top of the oil zone will be somewhat greater than if the structure were filled with water. In the assumed case it would be 678 pounds. Therefore, the peripheral pressure of the oil against the gas cap would correspond to that figure.

But gas is an elastic medium, which exerts pressure equally in all directions. Its reactive pressure downward against the oil would be the same as the upward pressure of the oil, in this instance 678 pounds, and this pressure would be uniform throughout the entire gas cap of the structure. Hence a well, "*C*," drilled to the gas area, will show at the casing head the same pressure as the reservoir pressure at the bottom of the well, which would also be the pressure of the oil-gas contact.

From this theoretical illustration the method becomes clear by which the characteristics of a pressure system may be established in actual practice. As an example, it will be assumed that the information available relates to a pool in essentially its original condition, that is, before its equilibrium had been disturbed by extensive extraction of oil and gas.

The following equivalents then appear:

Let w = specific gravity of water
s = elevation of sand at point cut by water well
h = elevation to which water rises
Then $h-s$ = rise of water
and $0.434\ (h-s)w$ = head of water in pounds = reservoir pressure
and

$$\frac{0.434(h-s)w}{0.434} + s = (h-s)w + s = \text{equivalent hydrostatic level}$$

But let
o = casing-head pressure = rock pressure of gas area at oil-gas contact
f = elevation of gas-oil contact
g = elevation of water-oil contact
n = specific gravity of oil
Then $f-g$ = structural depth of oil in feet
and $0.434\ (f-g)\ n$ = weight of column of oil equivalent to height of oil in structure
and $c + 0.434\ (f-g)\ n$ = total head of gas and oil in pounds
Whence

$$\frac{s + 0.434\ (f-g)\ n}{0.434} + g = \text{equivalent hydrostatic level}$$

If the conditions in the field are such that the oil rises in the casing unaccompanied by absorbed gas, the static level may be determined by the following:

Let h = height to which oil rises
s = elevation of sand at point cut by oil well
Then $h' - s'$ = rise of oil
Let n = specific gravity of oil
Then $0.434\ (h' - s')\ n$ = head of oil in pounds = reservoir pressure
But let g = elevation of water-oil contact
Then $h' - g$ = rise of oil above water-oil contact

and

$0.434\ (h' - g)\ n$ = head of oil in pounds above oil-water contact
= reservoir pressure in pounds at oil-water contact

Whence $\frac{0.434\ (h' - g)\ n}{0.434} + g = (h' - g)\ n + g$ = equivalent hydrostatic level

Of these equations for determining the static levels the first one is predicated on the existence of a well which enters the water-bearing part of the sand at the margin of the field. Such a well may not, of course, exist in every field, although it is not uncommon to find such edge-water wells. In the last equations exactness requires a knowledge of the elevations of the water-oil and oil-gas contacts. Where these are not previously known they may as a rule be approximated. Under most field conditions fairly close calculation of the position of the static level can generally be made by the application of the methods indicated.

Heretofore, in order to simplify the discussion, we have been dealing with an idealized condition, one in which constancy of pressure conditions throughout the structure was assumed. While this condition is probably characteristic, or nearly so, of oil-bearing structures in their original condition, the geologist seldom has an opportunity to make studies of pressure in the earliest stages of development, before the original condition of essential equilibrium has been disturbed. With the development of an oil pool these conditions, as has been pointed out, undergo rapid changes and the geologist or engineer may find out, when he is able to study the situation, that the conditions are quite different from those originally existing. The manner in which some of these changes take place will now be suggested.

CHANGES IN PRESSURE CONDITIONS DUE TO DEVELOPMENT

In the case of an artesian basin used for water supply, it would be expected that changes in pressure would occur as a result of drawing

upon the artesian supply. Wells which are drilled into the water-bearing portions of oil field sands are usually not utilized. Hence, the reservoir pressure in the water-bearing portion of the sand changes more slowly than in the adjacent producing oil and gas pool. Even after the field is developed, therefore, it is possible, by determining the static level in some water well, to approximate closely the original static level and thus compute the amount of the original reservoir pressure at that point in the structure.

On the other hand, the gas area, if there is one present on the structure, is most highly sensitive to changes in pressure conditions. If measurements of gas pressure were recorded at the beginning of the development of the sand, these would give another basis for determination of the initial static level. If a succession of measurements is made at later dates time graphs may be drawn showing the decline of rock pressure as a result of the extraction of oil and gas. The extrapolation of such a curve of pressure to the date of the opening of the pool gives another indication of the amount of the original rock pressure.

If by such methods the original conditions of rock pressure in the pool can be approximated then the changes due to development become evident. Much will depend, of course, upon the manner in which development has been carried out. If the gas area has been tapped and the gas freely withdrawn the progressive decline in gas pressure which would result from this extraction would reveal a corresponding decline in pressure in the reservoir. Instances of such decline are too common to require citation.

In the oil-bearing portion of the sand a similar decline in rock pressure will also occur with development. For the reason that the production of oil is ordinarily accompanied by the production of large volumes of gas, the conditions of rock pressure in this part of the sand are generally obscured. Measurements of casing-head pressure made of such wells show, as a rule, much lower gauge readings than in the adjacent free gas areas and such measurements, as has been previously pointed out, have been taken by many to indicate the actual reservoir pressure. If the actual reservoir pressure of such wells is measured or computed, it will be found to be much higher than the casing-head pressure. The apparent decline in pressure of such wells, as indicated by casing-head measurements, will therefore be greater than the actual decline.

If, for illustration, we assume that an oil and gas structure is developed uniformly and that both oil and gas are produced throughout

the area with regularity, then the decline in reservoir pressure in the developed portion of the area should be reflected by a change in the form of the static level. In the illustration (Fig. 4) the manner in which

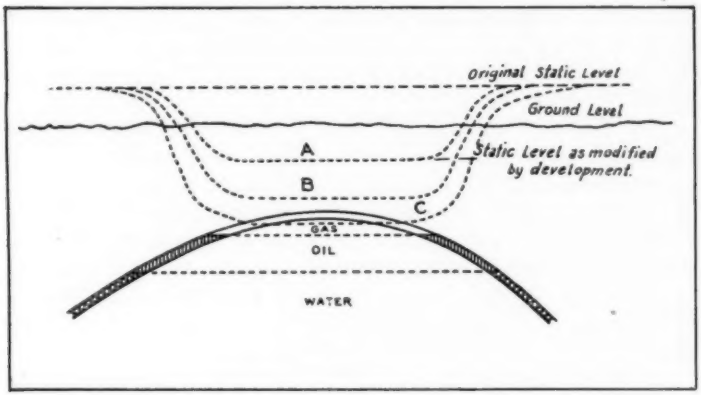

FIG. 4

this change takes place is diagrammatically suggested. Progressive lowering of the pressure in the gas area is indicated by the lines *A*, *B* and *C* and a stage is finally reached where there is little or no gas pressure in the central part of the structure. Outside the gas areas the static level develops a steep gradient, approximating its original height in the water area and sloping sharply toward the area of lower pressure. In fields where vacuum is used to increase oil production this pressure becomes negative.

With the creation of these differences in pressure a steep pressure gradient or strongly unbalanced pressure condition is established. The high peripheral pressure of the water against the oil which existed before the field was developed is still maintained, or undergoes only a gradual and slow decline. The neutralizing back pressure of the gas has, however, been removed. The resistance to upward and inward movement thus being reduced, water tends to occupy the zone of lower pressure, either forcing the oil before it or leaving it in part in adhesion to the particles of the sand.

In the beginning, while the back pressure against the perimeter of water is strong and the resistance to the motion of the water consequently high, water encroachment is very slow and scarcely detectable. With

the continued production of oil and gas and the continued decrease of the reservoir pressure in the portion of the sand above the water line, water encroachment tends to increase in rapidity. With almost the complete reduction of reservoir pressure which takes place in the advanced stages of development, the pressure gradient becomes very steep, the back pressure becomes negligible and the water will advance just as rapidly as it can overcome the frictional resistance in the sand.

CORRELATION OF MEASUREMENTS OF RESERVOIR PRESSURE IN CLOSED LENSES

In the portion of the preceding discussion which deals with the correlation of various measurements of reservoir pressure in the same oil-bearing structure there was taken as an example a pool in which the pressure was caused by artesian conditions. It was postulated that the sand had a regional distribution and that its outcrop was situated at such an elevation as to create hydraulic pressure in the sand as a result of the inflow of water.

Some oil fields are not, however, characterized by such artesian conditions. The sands may be lenticular in character and local in distribution, having no surface outcrop, hence no possibility of being filled with water from surface sources. They may contain water, oil, and gas under pressure, although the rock pressure existing in them must be ascribed to other causes than artesian conditions.

The general principles of gravitational distribution of water, oil, and gas which have been previously stated will generally apply in such cases. The basic difference is that the total amount of fluid which the sand contains is essentially fixed. There is no source from which any material amount of additional fluid may enter the sand. In contrast, therefore, with fields where artesian conditions are a controlling factor, the oil and gas extracted from such a lenticular sand is not ordinarily replaced by other fluids and the process of water encroachment which has been described is not effective.

There is no force present which tends to drive the water into those portions of the sand from which the oil and gas are removed. The reservoir pressure is primarily due to the presence of the gas confined within the sand lens much as is that in a soda syphon. As the gas is removed the pressure correspondingly decreases. With its complete removal the oil tends to go "dead" and the water in the sand, being no longer under pressure from the confined gas, also shows no further tendency to rise in wells. In other words, when the gas pressure is off the pool, the reservoir pressure has also been reduced approximately to zero.

In a sand of this character the initial conditions of pressure will be similar to those existing under artesian conditions. The same pressure system should exist throughout the lens, and it should be possible to correlate the measurements of pressure in the gas, oil and water zones of the sand just as though the pressure were due to artesian conditions. With development, however, the reservoir pressure in the water-bearing portion of the sand will decrease, instead of being maintained, as in an artesian field, by the inflow of additional water into the sand.

UTILITY OF STUDIES OF RESERVOIR PRESSURE

By the above discussion the author has endeavored to show that the pressure relations existing between gas, water, and oil in the same sand are consistent and may be definitely determined by the application of well-known principles of geophysics. It remains to suggest briefly the value which such studies may have in connection with oil-field investigation.

The study of pressure conditions in an oil field may be used in the correlation of sands, for if sands found in several adjacent wells show like pressure characteristics, the evidence points toward identity. Evidence of this nature may be used to complement that obtained by other lines of investigation,—for example, by water analysis. If an oil-bearing horizon is known to be stratigraphically continuous but wells drilled to the sand show sharp differences in pressure, it may be assumed that the pressure system of the sand has been disrupted, due either to faulting or to conditions of sedimentation which may have produced barriers in the sands. If, on the other hand, a sand is known to be faulted, the existence of the same rock pressure on either side of the fault may be an indication of freedom of communication across the faulted zone.

Most important, however, is its value in the investigation of problems related to the depletion of oil pools and to the encroachment of water. A clear understanding of the principles involved combined with careful field measurements should not only do much to increase our present knowledge of the manner in which exhaustion takes place, but should be of real value to oil operators in the management of their properties so that the maximum production may be obtained from the oil deposits.

VINTON SALT DOME, CALCASIEU PARISH, LOUISIANA[1]

S. A. THOMPSON[2] and O. H. EICHELBERGER[3]
Houston, Texas

ABSTRACT

The Vinton salt dome is a typical Gulf Coast salt dome. There is a mound at the surface with a central depression. The salt core is a little less than a mile in diameter. The north side is exceptional in that the salt dips downward to about 3,750 feet and then rises nearly 200 feet before dipping downward again. The lowest formation encountered is the Jackson. On the west and southwest sides of the dome the Oligocene has been pinched out by the Jackson due to the upward dragging effect of the salt core. Production is from the basal Fleming and Oligocene. The field has been one of the best paying fields in the Gulf Coast. The producing area is small with an enormous yield per acre.

LOCATION

The Vinton salt dome is in southwestern Louisiana in Calcasieu Parish 3½ miles southwest of the town of Vinton. The oil field is known both as the Vinton and as the Ged field.

Vinton is a town of 1,400 inhabitants on the main line of the Southern Pacific Railroad from Houston to New Orleans. All material and supplies are shipped here and hauled to the field over a good gravel road.

HISTORY

Vinton was the first of the salt dome oil fields in which oil was found on the flank of the salt dome. It was looked upon as a prospective oil field directly after the discovery of Spindle Top. Oil and gas seepages on the east side of the low marshy pond on top of the hill had been known for a long time. About a mile east of the hill there were springs containing sour waters similar to the waters at Sour Lake, Texas. Oil had been found in shallow water wells for several years.

The first well was drilled in May, 1901, near the bank of the east side of the lake under the supervision of A. Vincent. A showing of oil was reported at 320 feet, but due to a heavy bed of gravel, the well

[1]Manuscript received by the editor, December 27, 1927.

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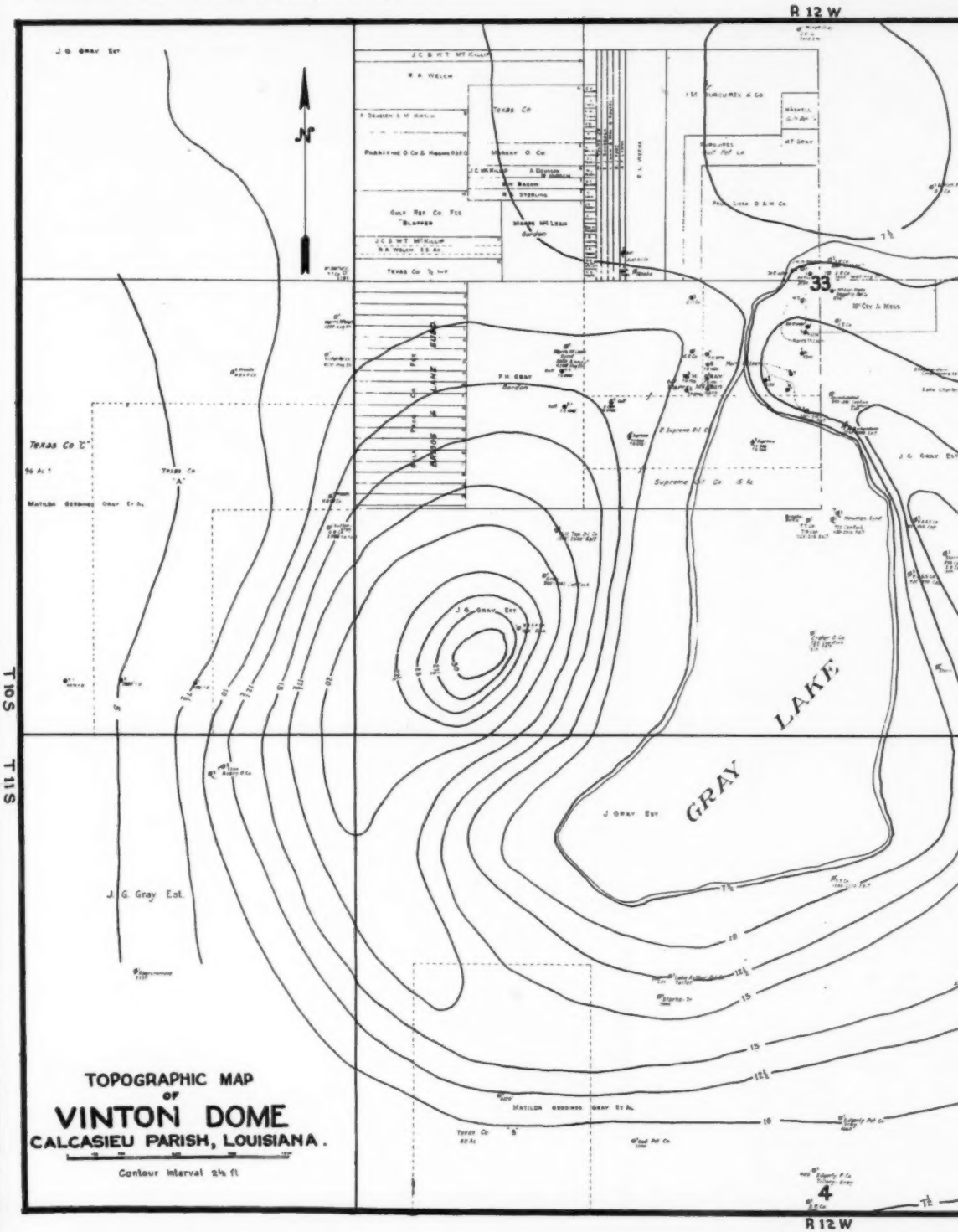
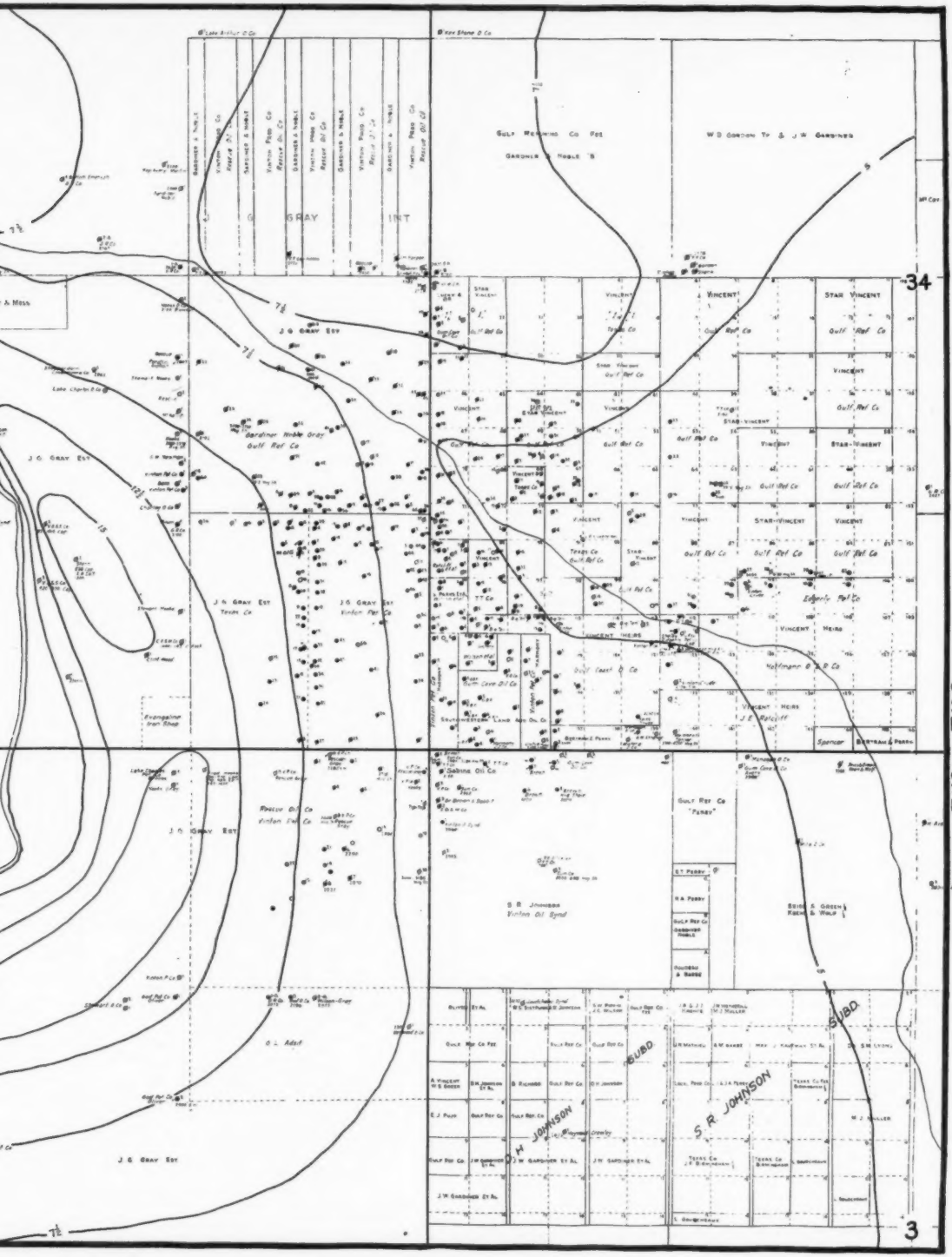
was lost at about 500 feet. The next well was located a little east of the first well and encountered oil at a depth of 26 feet. Several wells were completed at this horizon. They were pumped with an ordinary water-well pitcher pump and on the average produced 15 gallons per day. The oil was dark in color and very heavy but found a ready market at $7.50 per barrel at the local saw mills.

Other wells were drilled by Sharp and Prather and the Vinton Oil and Sulphur Company from 1902 to 1904. The drilling was nowhere deeper than 1,200 feet and resulted only in proving the presence of a salt dome.

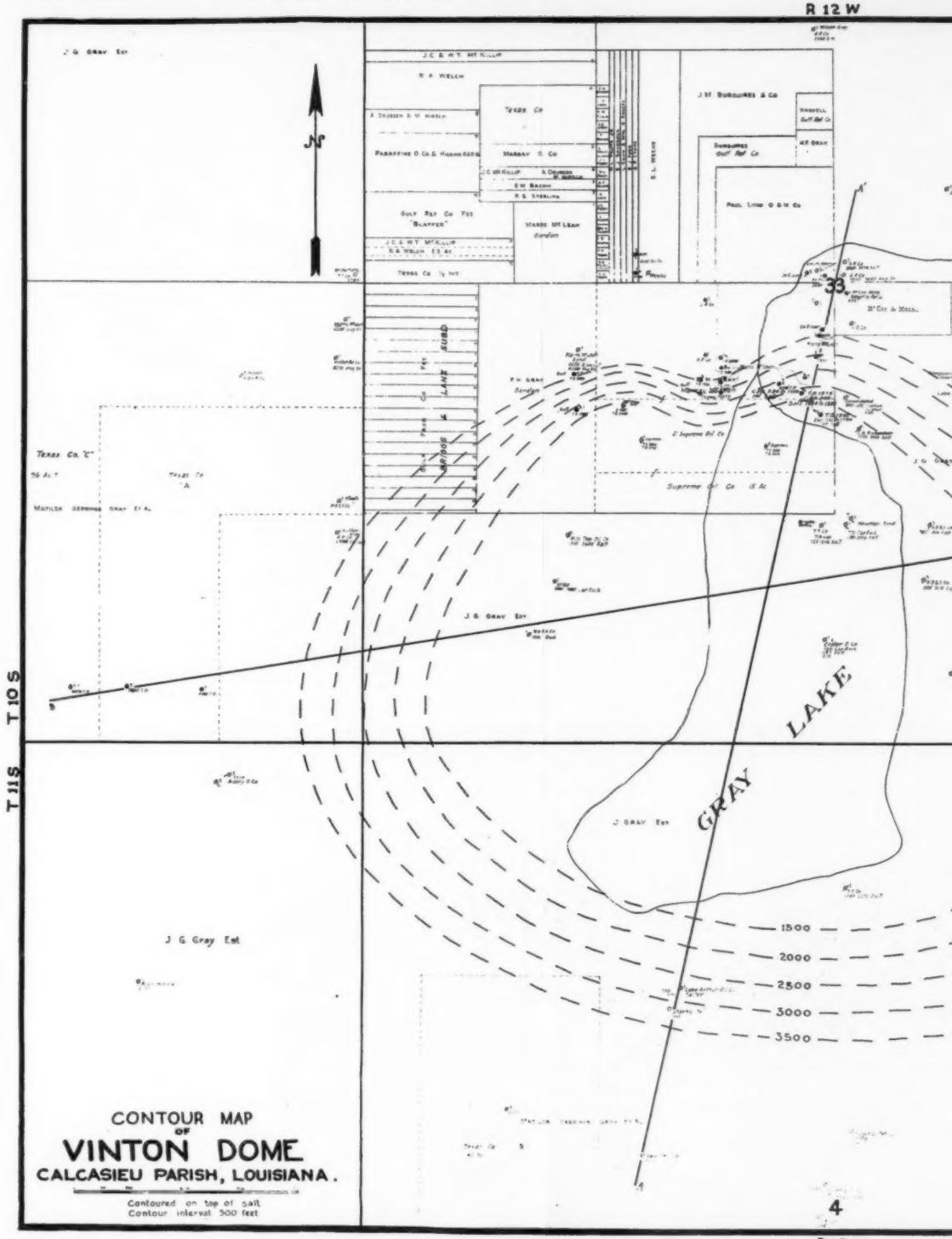
During 1904, five or six thousand acres of the land comprising this area were thrown into litigation and remained in the courts until 1910 before a settlement was made. After the closing of this litigation the area was again immediately leased and for the most part fell into the hands of the larger companies. Operations were started by the Gulf Refining Company of Louisiana, the Producers Oil Company (now The Texas Corporation), the Sabine Oil Company, G. W. Hooks *et al.* and the Ninety-Nine Oil Company. The Sabine Oil Company's Johnson No. 1 was the first completion. This well was located in the northwest corner of the Johnson lease in the southeastern part of the field and came in flowing by heads 100 barrels daily. The first large well was the Gulf Refining Company-Producers Oil Company's joint test No. 1 which was completed in July, 1910, with an initial daily production of 2,100 barrels. This well was located in the extreme southwest corner of lot No. 75 of the Vincent subdivision and is usually spoken of as the discovery well. It is said to have shown water from the first but flowed for more than two months. The month following the Gulf Refining Company completed its Gardiner, Noble, and Gray No. 1 in the southeast corner of the NE. ¼ SE. ¼ of Sec. 33. T. 10 S., R. 12 W., with an initial daily production of 3,000 barrels of pipe-line oil. This completion was followed early in September by the Vinton Petroleum Company's Gray No. 1 in the southeast corner of the same section, which after flowing for a short time was placed on the pump. During the next few months until the close of 1911 Vinton witnessed a sensational boom. Development was very rapid and by the time the field was 18 months old it had produced 2,480,804 barrels of oil. From then on the production gradually declined due to the natural decline of the wells and the more conservative development policies of the larger companies into whose hands most of the properties had fallen. In 1917 the field was again the scene of renewed activity for a few months after the



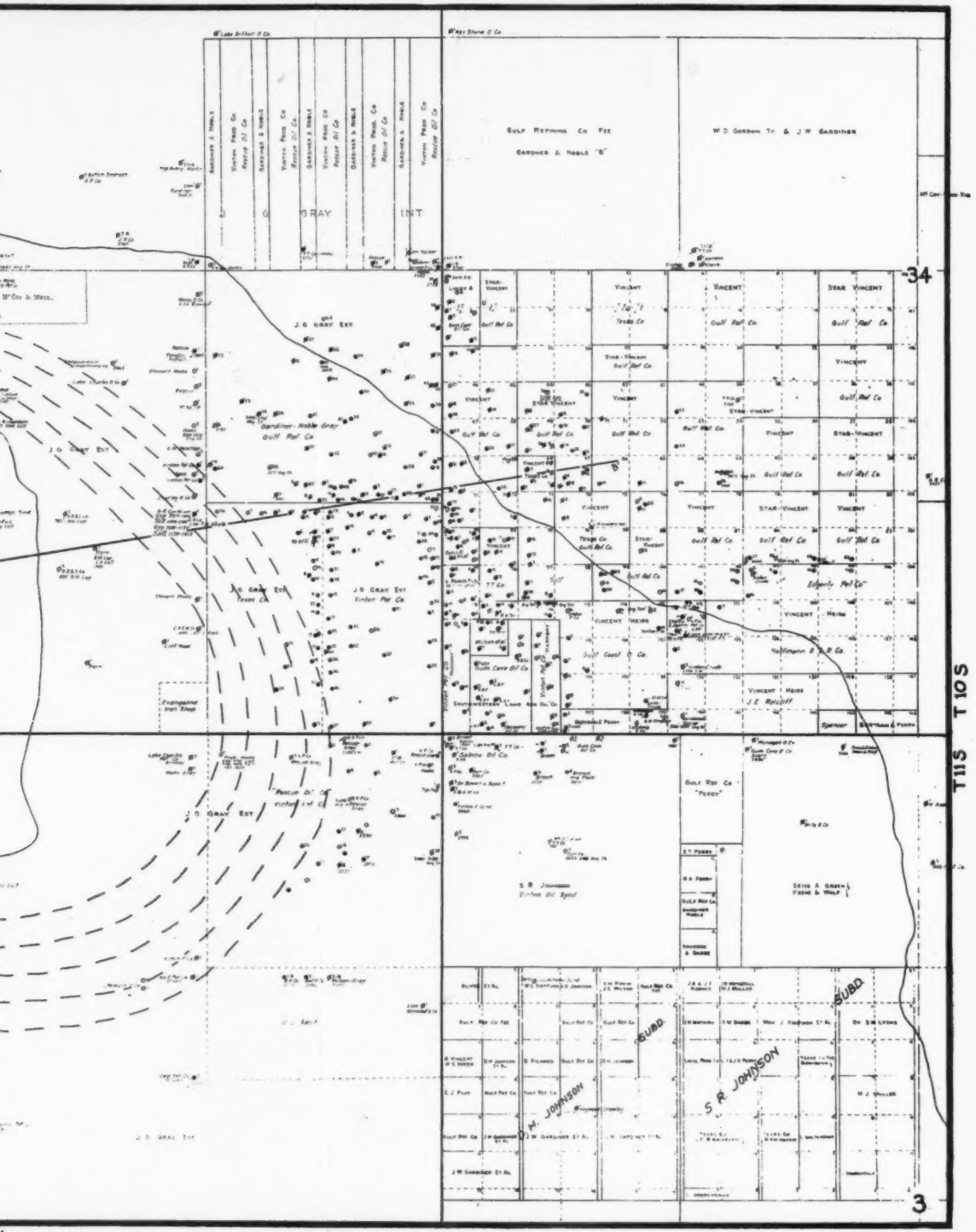
Topographic map of Vinton salt do



Vinton salt dome. Scale in feet.



Map of Vinton salt dome. Contours on t



Contours on top of the salt. Scale in feet.

Gulf Coast Oil Company completed its Vincent No. 7 in lot No. 119 of the Vinton subdivision for 18,000 barrels.

Operations at the present consist chiefly in working over old wells and the occasional drilling of new wells in the proved area. In addition, from time to time some optimistic operator ventures to drill a well outside of the old field.

No sulphur has ever been found in commercial quantities on this salt dome and as yet no effort has been made toward the production of salt.

PHYSIOGRAPHY

Vinton lies within the flat Pleistocene Coastal Plain of Louisiana, which extends 40 to 60 miles back from the Gulf of Mexico. With the exception of a few scattered salt dome mounds this plain is almost featureless. Sabine River on the west and Calcasieu River on the east have traced their courses southward across the plain but neither they nor their tributaries have effected any noticeable erosion.

The Vinton mound is a characteristic central sunken type dome, such as Palangana and West Columbia (Plate 3). The sink is defined by a fresh-water pond known as Gray Lake. The lake is on the summit but has an outlet on the north which extends 800 feet in a northerly direction and then turns toward the south. Except on the north, the lake is surrounded by a low circular ridge, the highest point of which is on the west side, where the elevation is approximately 30 feet above sea-level and about 15 feet above the general prairie.

GEOLOGY

SURFACE GEOLOGY

The beds exposed at the surface in this general region belong to the Port Hudson series, of Pleistocene age, which in Texas is known as the Beaumont clay. They are composed of sands and clays. The mound, however, has a more sandy soil than the surrounding territory.

SUBSURFACE GEOLOGY

Vinton is a characteristic salt dome with a core of massive rock and rock salt (Plate 4). The rock is above the salt and consists of limestone followed in depth by gypsum and anhydrite which are cavernous in places and filled with sulphur water. Several wells have been drilled on the dome, but there is not sufficient information available to determine what amount of the rock is limestone, gypsum, or anhydrite. Samples of old cores picked up near wells on the north part of the dome

show a rather characteristic fine-grained cap-rock limestone permeated by a network of fine solution channels.

The salt core is approximately 4,200 feet wide from north to south and 5,000 feet long from east to west. The highest elevation at which it has been found is 925 feet below sea-level near the north end of Gray Lake. The east and north flanks of the salt core are irregular, as shown by the Gulf Refining Company's Wilson No. 1 in the northeast corner of the SW. ¼ SE. ¼ of Section 33, which encountered gypsum from 957 to 1,106 feet, salt from 1,106 to 1,140 feet, gypsum from 1,140 to 1,170 feet, salt from 1,170 to 1,413 feet, and black heaving shale from there on to 2,100 feet, where the well was abandoned. Hooks' Producers No. 1, located 1,290 feet south of the Wilson well, is reported to have encountered gypsum from 836 to 970 feet, salt from 970 to 989 feet, gypsum from 1,557 to 1,582 feet, and salt again from 1,582 to 1,620 feet, where the well was abandoned. On the north about 500 feet south of the center of Section 33, Marrs McLean's Gray No. 1 and No. 3 passed through a ledge of salt followed by sands saturated with oil. These wells are located on what might be termed a protruding ledge of the salt, the true edge being defined by the Gulf Refining Company's Gray No. 2 in the southwest corner of the NE. ¼ of Section 33. This well encountered the salt at 3,560 feet and drilled in it to 3,974 feet, where the well was abandoned, though just 50 feet toward the south Gray No. 1 failed to find salt as deep as 3,690 feet (Fig. 1).

A west to east section (Fig. 2) across the dome shows the top of the salt sloping unevenly toward the west and the sides very steep from about the 1,400-foot level. In places it is probable that the actual dip of the sides of the salt is nearly vertical. The thickness of the salt mass is unknown. No drilling has ever been done to make a determination, but from explorations conducted on other domes, it is no doubt greater than 5,000 feet.

The cap rock is well defined and probably extends over the top of the entire salt mass. On the Marrs McLean lease on the north side it is approximately 700 feet thick and projects out over the salt as a protruding shelf. In the center of the dome it has a thickness of about 400 feet, although on the south it has thinned to 245 feet. Its highest elevation below sea-level is approximately 500 feet at Marrs McLean's Gray No. 1.

The nature of the super-cap beds is not well understood due to the lack of information from the wells which have been drilled on top of the dome. Their uppermost portion consists of Pleistocene sands,

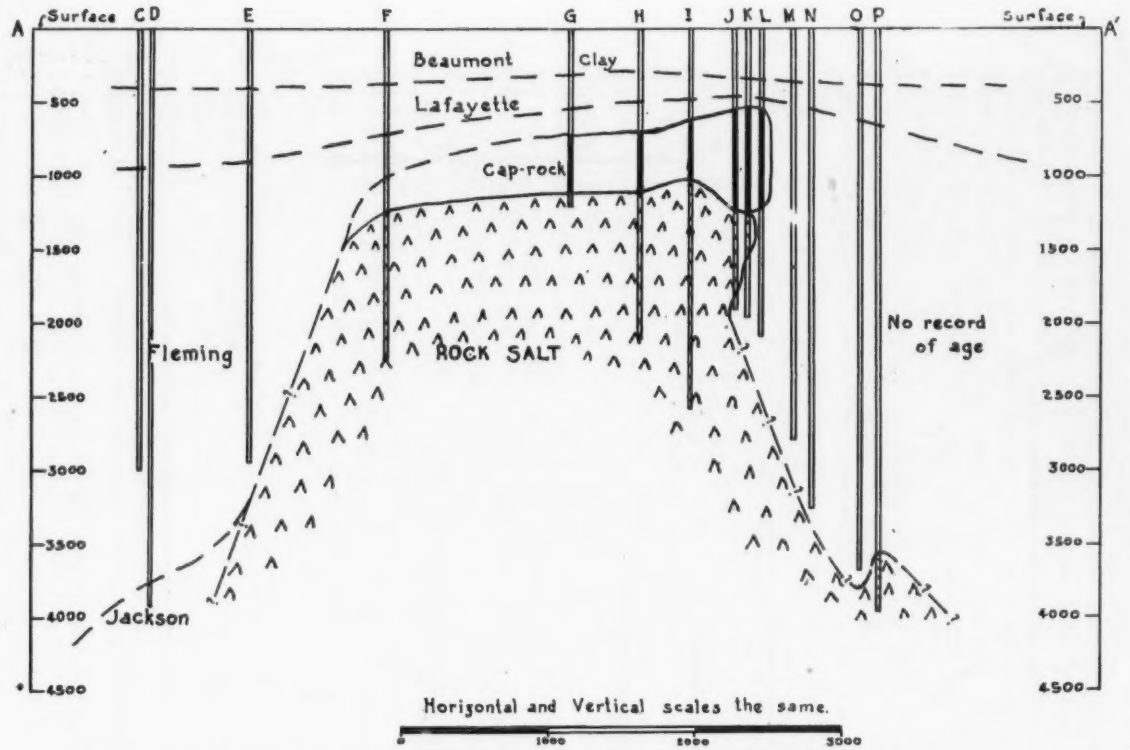


FIG. 1.—Section of Vinton salt dome along the line *A-A'* of Plate 4. *C*, Ged Petroleum Company's Gray No. 1; *D*, The Texas Company's Gray No. B-1; *E*, Starks Trust's Gray No. 1; *F*, The Texas Company's Gray No. 1; *G*, Carter Oil Company's Gray No. 1; *H*, The Texas Company's Brooks and Bettis No. 1; *I*, Supreme Oil Company's Gray No. 2; *J*, Marrs McLean's Gray No. 3; *K*, Marrs McLean's Gray No. 1; *L*, Marrs McLean's Gray No. 4; *M*, Marrs McLean's Gray No. 6; *N*, Marrs McLean's Gray No. 5; *O*, Gulf Refining Company's Gray No. 1; *P*, Gulf Refining Company's Gray No. 2. Scale in feet.

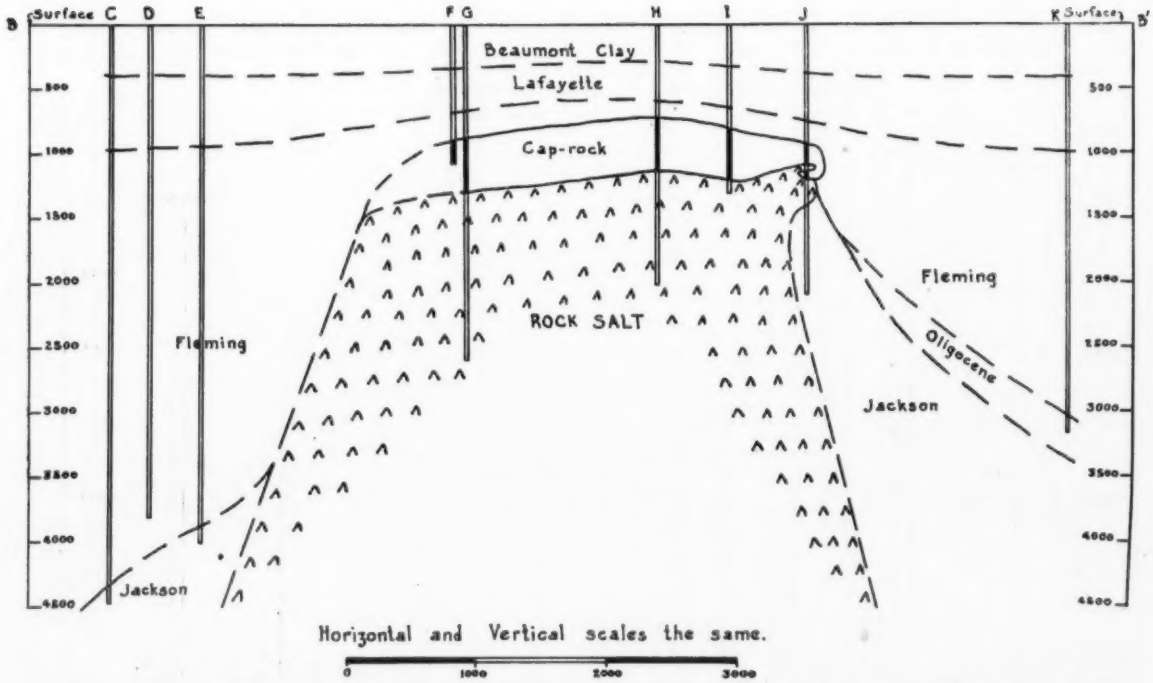


FIG. 2—Section of Vinton salt dome along the line *B-B'* of Plate 4. *C*, The Texas Company's Gray No. C-1; *D*, The Texas Company's Gray No. A-2; *E*, The Texas Company's Gray No. A-1; *F*, Gray; *G*, Hill Top Oil Company's Gray No. 1; *H*, Newman Syndicate's Gray No. 1; *I*, Stern's Gray No. 2; *J*, Gulf Refining Company's Wilson No. 1; *K*, Gulf Refining Company-The Texas Company's Vincent No. 1. Scale in feet.

gravels, and clays, but the basal members may belong stratigraphically several thousand feet below their present position. On the flanks of the dome these Pleistocene sands and gravels have a very gentle slope. Their base is between 900 and 1,000 feet deep over the producing area. The beds beneath are inclined very sharply against the salt. The rate of dip varies, depending upon the local upward dragging effect of the salt plug.

The sediments off the dome are composed of sand, shale, gumbo, rock (consisting chiefly of cemented sands), and heaving shale. Several wells around the dome have encountered this shale. It is black and full of oil and gas which constantly cause it to rise hundreds of feet into the hole of a drilling well. To date no successful method has been devised to drill through it. This shale rests against the salt, dips outward from the dome, and is definitely known to underly the entire productive area on the east side.

STRATIGRAPHY

Beaumont clay.—The first 200 feet below the surface is composed of sand and clay and has been called the Beaumont clay, or the Port Hudson, of Pleistocene age. The exact thickness and base of this formation are difficult to determine. Heavy sands and gravels make their appearance at 400 feet and this should mark the approximate base.

Lafayette gravel.—Beneath the Beaumont clay are the Lafayette sands and gravels which are late Pliocene and possibly early Pleistocene in age. Though this formation is called gravel, it carries sand and a small amount of shale and gumbo. It has a thickness of about 600 feet and is found in few places below 1,000 feet.

Fleming clay.—Underlying the Lafayette gravel is the Fleming clay. That it is undifferentiated Miocene and Pliocene is as accurate a statement as can be made of its age at this time. It is composed chiefly of gumbo, with some sand, though the amount of sand varies from well to well. The Fleming ranges in thickness from a few hundred feet on top of the dome to approximately 3,000 feet on the flank.

Oligocene.—The Oligocene lies beneath the Fleming and is composed chiefly of sands and sandy shales. On the west and southwest sides of the dome it is absent (Fig. 2) This does not necessarily indicate an unconformity but is probably due to the fact that the lower Jackson shales have been dragged up by the salt core and have pinched out, near the dome, all the Oligocene that was originally present. It is also thought that part of the Oligocene has been irregularly pinched out on the east side in the same manner. The thickness of 300 feet in the cross-section is only a rough estimate because no good records are available.

Jackson.—The Jackson follows the Oligocene in depth. It is of Eocene age and when encountered is, as a rule, in the form of heaving shale. There is no information regarding its thickness since no wells have been drilled through it.

OIL

The oil produced in the Vinton field is a typical Gulf Coast crude, ranging in gravity from 19° to 37° Bé., with a green color. The oil from the sands of 1,900 to 2,300 feet has an average gravity of 19.2° Bé., and that from the sands beyond this depth has an average gravity of 22° Bé. A few wells on the edge of the salt and several completed near the top of the heaving shale are reported to have found a light oil with a "paraffine" base. This so-called "paraffine" in places forms as an asphaltic wax which must be steamed off the rods and out of the tubing. In the southeast corner of the NE. ¼ of Section 33, the Vinton Petroleum Company completed a 300-barrel well of 37° Bé. gravity oil from a sand at 3,385 feet just above the top of the heaving shale. This is the highest gravity reported for the field.

PRODUCTION

The producing sands range from 1,900 to 3,400 feet in depth. They are basal Fleming and Oligocene in age.

Some of the best wells which have been completed in the Gulf Coast have been at Vinton. Many of the early wells had an initial production ranging from 1,000 to 10,000 barrels from the shallow sands. The largest well ever completed was the Gulf Coast Oil Company's Vincent No. 7 in lot No. 119 of the Vincent subdivision, with an initial daily production of 18,000 barrels of pipe-line oil from 2,828 feet. The gas pressure in the sands was high in the early life of the field, and many of the wells flowed for a year after completion. The record is held by the Gulf Refining Company's Gardiner, Noble, and Gray No. 22 in the NE. ¼ SE. ¼ of Section 33, which flowed for 3 years lacking 5 days. The Vinton Petroleum Company's Gray No. 2 in the SE. ¼ of Section 33 is another remarkable well in that it was still pumping after having produced for 13 years from the original screen setting without a single work-over. Nearly all wells now completed must be pumped on account of the low gas pressure. However, several of them produce sufficient gas to furnish fuel for pumping with gas engines.

Vinton, unlike many of the Gulf Coast fields, has had very few violent gas wells. The Gulf Refining Company's Star Vincent No. 24, in lot No. 63 of the Vincent subdivision, is the record gas well, with an initial production of 10 million cubic feet from 3,475 feet. The total

number of blow-outs for the entire field probably does not exceed ten.

The producing area has been confined to the east, northeast, and north sides of the dome, containing approximately 150 acres. Several wells have been drilled on other parts of the dome and have yielded some oil, but they are not commercially important. On the west the Gulf Refining Company drilled Sutton No. 1 to a depth of 2,499 feet. No showings were reported and the well was abandoned without a test. The Texas Company drilled three wells on its Gray lease with very little success. To the north of the field in the southeast corner of the NE. ¼ NW. ¼ of Section 33 the Gulf Refining Company drilled Wilson-Gray No. 1, which was abandoned at 2,200 feet. Since the completion of Marrs McLean's Gray No. 5, several producing wells have been drilled in this vicinity. No well has been drilled to test the southwest quadrant of the dome. Very few deep tests have been drilled in the field thus far.

The cost of production per barrel has been very low, which is explained in part by the high recovery per acre. In October, 1917, one of the large companies produced oil as low as 9 cents per barrel.

The total production of the field to the first of January, 1928, has been 29,485,402 barrels, or an average of 196,569 barrels per acre. At the close of the year, 1927, it had a daily production of approximately 4,750 barrels. The annual production has been as follows:

VINTON DOME, ANNUAL PRODUCTION

Year	Barrels
1910	26,701
1911	2,454,103
1912	932,639
1913	1,888,664
1914	1,465,302
1915	1,234,227
1916	1,540,147
1917	1,595,366
1918	1,839,083
1919	1,592,000
1920	1,333,000
1921	1,379,000
1922	1,395,000
1923	2,071,000
1924	1,968,000
1925	2,535,000
1926	2,344,000
1927	1,892,170
Total	29,485,402

NOTES ON OPERATIONS

Operations at Vinton have been conducted in the same manner as in the average coastal field. All wells are drilled with rotary rigs. As a general rule operators set about 1,000 feet of 10-inch casing and about 1,800 feet of 6-inch casing. The well is then finished with 4½- or 4-inch screen of 60 to 80 mesh.

Most of the production is run by the Texas Pipe Line Company. The Gulf Pipe Line Company also has a line to the field but carries little oil other than that produced by the Gulf Refining Company.

ACKNOWLEDGMENTS

The writers wish to make the following acknowledgments: to the Gulf Refining Company, The Texas Corporation, the Vacuum Oil Company, and the Rycade Oil Corporation for data furnished from their records, to J. C. Miller and D. C. Barton for helpful suggestions and to Paul E. Nash for the drafting of the maps and cross sections.

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PANUCO OIL FIELD, MEXICO[1]

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ABSTRACT

A comprehensive paper dealing with the geology, structure, and conditions of oil occurrence in the Panuco field.

INTRODUCTION

Panuco, with its production of 500,000,000 barrels of oil in the years 1910 to 1926, inclusive, is one of the world's greatest oil fields. The producing area comprises about 300 square miles and is generally divided into five sections: Panuco proper and Topila on the south, and Ebano, Cacalillao, and Corcovado on the north. An additional area of about 200 square miles on the north contains many seepages and during 1926 two producing wells were developed in the Altamira Hacienda in the northern seepage district.

Panuco is unique in its combination of some of the characteristics of a metal mining district with those of an oil field. Igneous intrusions and contact metamorphism have been operative; consequently, the occurrence of oil in great quantity goes far to discredit if not entirely to disprove the carbon-ratio hypothesis. Igneous effects have greatly modified the oil, gas, and water and appear to be largely responsible for the following peculiarities: (1) the oil is very heavy in gravity and high in sulphur content, (2) the gas is mainly carbon dioxide with an important percentage of hydrogen sulphide and is not so readily exhausted as in most other fields, and (3) the water contains the highest percentage of potash salts yet found in any water occurring directly with oil.

There are in addition other peculiarities partly explainable by igneous intrusive effects and structural characteristics. The profitable oil occurs in limestones and only in fracture zones in the limestones which are otherwise so impervious that they are practically barren. Accordingly, all wells drilled in producing areas are wildcat, the far

[1]Presented by title before the Association at the New York meeting, November 17, 1926.

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greater number being failures. The profitable oil is not confined to any definite geologic horizon. No top or edge waters proper are found. All wells flow during the entire period of profitable production. No profitable method for separation of emulsion or bottom salt water from the oil has yet been found.

The field is situated on the south-plunging end of the Sierra de Tamaulipas—Sierra de San Carlos anticline. This anticline is about 235 miles in length with a breadth ranging from 35 to 60 miles. The breadth of the area at present producing is 15 miles in the direction normal to the major anticlinal axis. The oil-bearing Cretaceous formations are exposed in the mountainous portion of the Sierra de San Carlos and Sierra de Tamaulipas, but extremely few seepages occur on the outcrop. There are several minor folds in the producing area, but the points of highest structure have proved extraordinarily barren and at least one of the deeper of the minor synclines has yielded large production.

ACKNOWLEDGMENTS

Experience has demonstrated the great difficulty if not virtual impossibility of solving the major Panuco problems without the study of a large part of the contiguous area of northeastern Mexico in which actual exposures afford indispensable data on stratigraphy, structure, and igneous activity within the field itself. The study of the environs has proved an arduous and expensive task for the writer during parts of the years 1920, 1921, 1924, and 1925. The work would have been impossible without the important financial aid of L. E. Hanchett of Los Angeles and of the Southern Pacific Company through E. T. Dumble and H. B. Titcomb. These gentlemen possessed the broad viewpoint unfortunately so rare among oil producers, yet so essential for their real interests; they considered it best to permit the geologist to be his own judge of what it was necessary for a geologist to accomplish. In this paper the writer presents only results of those researches which are judged to have important bearings on Panuco field problems.

Every worker in the Panuco field owes a tremendous debt to the pioneer efforts of W. F. Cummins who, ripe in years and experience, with a surety of judgment equalled by few and with indomitable will at a time in life when most men have retired from active work, discovered and began the development of both the Panuco proper and Topila sections and located and drilled the discovery well of the Mendez-Corcovado section. It is worthy of record here that the two other oil fields of Mexico, the Southern or Golden Lane and the Isthmus of Tehuan-

tepec, were discovered by drilling on extensive seepages by the precise procedure used by a mineral prospector in finding an ordinary mineral deposit, whereas in each of the Panuco and Topila sections there existed but a single insignificant seepage which the ordinary geologist even to-day would esteem of little importance. Furthermore, the first wells which Cummins drilled at Panuco and Topila proved profitable producers, a most remarkable achievement viewed in the light of subsequent events. In 1910, the discovery year of the northern fields, Cummins, from a study of outcrops on the Rio de Las Virgenes and Canyon San Bartolo, in the mountains of western Tamaulipas, reached the conclusion that one of the sources, if not the main source, of the oil of the Tampico region is the Upper Jurassic.

It was not until June 1, 1926, or 19 years after the beginning of active development, that the San Manuel deep test demonstrated the correctness of his view. Cummins' policy of carrying every well in the field to a depth at which either profitable oil or salt water is encountered is one which, judged from results still being obtained on East Coast Oil Company leases, had best be given far more serious consideration than is generally being done just at present. It was under Cummins' direction, also, that the first well was "shot" in Mexico and "shooting" of wells is another matter which must be taken far more seriously in the future of the Panuco field.

It is well to recall, also, that the East Coast Oil Company, with which Cummins, Dumble, and the writer have been associated, was the first to demonstrate, with the opposition of much opinion to the contrary, the practicability of transporting the heavy Panuco crude through a pipe line, and that this same company has a record for efficiency and economy of operation which has not been equaled by any other company of equal scope in Mexico.

It is most unfortunate for petroleum geology, in the progress of which the elucidation of Panuco problems is of exceptional importance, that the present paper could not be written by John M. Muir, whose detailed knowledge of the field is far more extensive than that of anyone else. The writer must apologize for great defects in his knowledge of the oil field itself. It has not been possible for him to devote much effort to any but the Panuco section proper and, to a far less extent, the Topila section. He has, however, been greatly aided by other geologists of the Tampico region, who have accorded him the fullest coöperation. It is perhaps invidious to make special acknowledgment to any where all have contributed so much but mention may be made in particular of

John M. Muir, W. A. Baker, Jr., Paul Weaver, Walt M. Small, W. F. Cummins, and E. T. Dumble.

SURFACE FEATURES

Strata of upper Oligocene or lower Miocene age outcrop on the east and south flanks of the upper or productive part of the major anticline but only at Topila within the area of present production. The innermost exposures of these strata form escarpments above the flat lowlands of the main present producing area. Panuco River, an extremely tortuous and meandering stream, flows east through the field and has excavated a valley bottom averaging 20 miles across. Many former channels of the river as well as channels filled only during times of flood are the sites of permanent or temporary lagoons, tidal estuaries, bayous, and swamps. During the months of July to January, inclusive, most of this bottom land is either covered with water or so muddy that heavy transportation is nearly impossible. The tide extends up the river for several miles farther west than the oil field. The river alluvium is mostly from 100 to 250 feet in depth. It consists of fine silty and sandy material derived from the erosion of Cretaceous marls and limestones and Velasco and Eocene shales and sandstones, and of local lenticular layers of chert gravel derived from Cretaceous limestone in the mountains. In the eastern part of the field the silts and gravel contain brackish-water shells. The silts and gravels have filled, in part, a former embayment of the gulf and in part a broad lowland which has gradually sunk as deposits accumulated.

In that part of the northern sections occupying the divide between Panuco and Tamesi rivers the Pierre and Velasco marls are exposed and the topography is very gently rolling, with broad, low, smooth-contoured hills.

In Ebano are two abrupt knolls of higher elevation, outcrops of basaltic intrusions. Remnants of gravel terraces form a few low hills or broader upland flats in the Panuco valley.

In Lafayette time a peneplain was developed over many thousands of square miles. A second and lower stage of peneplanation is now well advanced and its formation has been extensively aided by a recent downwarp of the land. In addition to the hills and ridges already mentioned, monadnocks rising above the general level owe their existence to the superior resistance of their basaltic rocks. The Sierra de Tamaulipas proper is flanked by outwash gravel fans of Lafayette age which have been firmly cemented with caliche. Most of these fans are in process of a dissection which has long been active.

Erosion is a relatively rapid process in the loosely consolidated Upper Cretaceous and Tertiary rocks of most of the region, rainfall is both torrential and plentiful, and there are reasons for thinking that the dense scrub jungle which now covers most of the land not now subject to overflow, and which inhibits erosion, was perhaps less extensive in former times.

STRATIGRAPHY OF THE PANUCO SECTION PROPER

So far as known, the stratigraphic succession consists of a formation, the Velasco, of either Upper Cretaceous or lower Eocene age, a full section of the Cretaceous from the top of the Pierre to strata older than the lower Trinity of the Texas section, a portion of the Upper Jurassic, a limestone of unknown age separated by a conglomerate from the Upper Jurassic and Red beds of unknown age separated by an unconformity from the overlying strata. There is possibly at Altamira an unconformity separating the Upper Jurassic from the pre-Trinity Cretaceous, but Jurassic and Cretaceous are probably conformable under the present field. It is very probable that the Cretaceous section is conformable throughout. Volcanic tuffs are plentiful from the base of the Benton to the top of the Pierre Cretaceous and may occur in the Kimmeridge Upper Jurassic. The section which will be described is that of the Panuco section proper.

CORRELATIONS

The Upper Cretaceous of northeastern Mexico is most closely related to strata of the same age in the Great Plains and Rocky Mountains of the United States. Equivalent strata have been given other names in Texas but the Texas names are superfluous, contrary to the rules of priority, and tend to confuse the reader. The upper part of the Mexican Lower Cretaceous is closely related to the Comanchean Cretaceous of Texas and for this part Texas names will be used. However, the lowest part of the Mexican Cretaceous is not represented in Texas except in a small area in the Malone Mountains where it is not yet satisfactorily differentiated paleontologically. For this part of the Mexican section there is no satisfactory alternative except to use the standard European nomenclature which also is most suitable for the marine Upper Jurassic.

A two-fold division of the Cretaceous into Upper and Lower is used, following the usage of most American authors. The dividing line is taken at the base of the Benton of the standard American section, or

of the Turonian of the standard European section. The three-fold division of the Cretaceous into Lower, Middle and Upper, as used by Haug and others for Europe, is really the most suitable for Mexico, but with this classification the dividing line between Lower and Middle is drawn within the Trinity or lowest group of the Texas Comanchean. The pre-Trinity stages of the Mexican Cretaceous in descending order are the Barremian, the Hauterivian, the Valanginian, and the Berriasian. The Hauterivian and Valanginian have generally been grouped together in Mexico and the Berriasian basal stage of the Cretaceous is not, so far as known, plentifully fossiliferous and has sometimes been described as Jura-Cretaceous transition beds.

Up to the present only the Upper Jurassic is known in the marine section of northeastern Mexico. This is divided, as usual, in descending order, into the Portland, Kimmeridge, and Oxford.

VELASCO BENTONITIC MARL

Velasco, the type locality of this formation, is a station of the Tampico-San Luis Potosi Railway west of the Ebano sector. None of the Velasco formation is found in localities of highest structure in the Panuco field, but the lower part of it is found directly beneath the alluvium in most of the field.

In lithology the Velasco in the wells differs little, if at all, from the underlying Pierre. The age of the Velasco is in doubt since foraminifers are the only fossils known in it. Some geologists and micropaleontologists think it may be separated from the Pierre by an unconformity, but the unconformity has not been proved and the question can be settled definitely only by continuously coring the necessary interval in several wells. A partial attempt has been made to do this in two East Coast wells. In these no appreciable difference in lithology could be detected, and no evidence of a stratigraphic break was found between the lower Velasco and the upper Pierre.

It is not certain that what has been called Velasco on the outcrop is the same as what is called Velasco in the wells. The main outcrop area of the Velasco is the great geosyncline between the Sierra de Tamaulipas anticline and the eastern front ranges of the Mexican cordillera proper (Sierra Madre Oriental). Here the strata contain considerable detritus derived from erosion of land areas. At the foot of the western flanks of the Sierra de Tamaulipas and Sierra de San Carlos this facies of so-called Velasco rests unconformably upon the Pierre. The best outcrop section known of what has been regarded as Velasco east of the

Sierra de Tamaulipas anticline is exposed on Soto la Marina River between the towns of Soto la Marina and Abasolo, and here the strata do not contain the land-derived detritus and are practically indistinguishable from the underlying Pierre. However, the land at the time of deposition of the strata in the geosyncline lay at the west in the present Mexican cordillera region, and detrital material may not have been transported so far east as the eastern foot of the Sierra de Tamaulipas.

West of the geosyncline and easternmost front ranges in the country traversed by the Tampico-San Luis Potosi Railway, between the head of the Tamasopo Cañon and the Puerto-Villar Pass, which includes the Gardenas area, the Pierre is overlain conformably by Fox Hills strata which contain the most plentiful and diversified fauna known in the Mexican Cretaceous. The Fox Hills strata there contain calcareous sandstone beds, some fine conglomerates, and a large amount of sandy and argillaceous shale and marls.

Neither these Fox Hills strata nor the so-called Velasco strata of the geosyncline contain any volcanic tuffs. This is significant since the Pierre of all these regions and the so-called Velasco penetrated by the drill at Panuco contain volcanic tuff in large amounts.

The micro-fauna of the type section in the vicinity of Velasco station has been studied by several micropaleontologists, but they do not agree upon its age. Some refer it to the Fox Hills (Navarro) of the Upper Cretaceous; others judge it to be lower Eocene of various stages from Midway to Claiborne. It would be premature to accept the judgment of any of these since the true value of foraminifers alone in making long-distance age correlations remains to be proved within restricted areas. Foraminifers have proved valuable for local correlations, but this phylum of animals is susceptible to bottom and water conditions, effects of currents, and changes of temperature, like any other, and it is really only exceptionally that a single class of invertebrates, like the graptolites or ammonites, can be confidently trusted for long-distance correlations.

In brief, therefore, the strata termed Velasco within the Panuco producing area may be either upper Pierre or lower Fox Hills in age, or possibly lower Eocene, in which latter case a considerable break in time must separate them from the underlying Pierre. Lithologically, they evidently belong to the Upper Cretaceous conformable sequence.

UPPER CRETACEOUS, ITS NOMENCLATURE, CORRELATION AND THICKNESS

Strata certainly known to be Upper Cretaceous will here be divided into the Benton, Niobrara, and Pierre, the original names for these formations in the western interior region of North America. There is no doubt that the formations so named in the Panuco district are substantially equivalent to those of the same names in the Great Plains and Rocky Mountains. We have already noted that the Pierre is conformably overlain by very fossiliferous Fox Hills in the Mexican mountainous region west of the Panuco field. The formation referred to the Benton has yielded the characteristic fossil *Inoceramus labiatus* both from Panuco wells and outcrops on the north and west. These Benton beds in the easternmost Mexican front ranges are known to overlie the Buda with *Pecten rœmeri*. Outcrops in the Sierra de Tamaulipas of the strata here referred to the Niobrara have mosasaur bones and the giant Niobrara *Inoceramus* of western Kansas and the Rio Grande.

The formations as here delimited very possibly do not exactly coincide in upper and lower limits with those of the Upper Cretaceous type region. They could scarcely be expected to be the exact lithological equivalents and large fossils are very conspicuously rare in these formations in this part of Mexico. What we have chosen as most suitable for the top of the Pierre may not prove to be the exact top and most of the micropaleontologists consider what we here group with the Pierre, as its lower part, to be upper Austin of the Texas section. What is of most utility for our purposes is the grouping of the strata into the most logical lithologic units. It has been demonstrated beyond doubt that in this part of Mexico the three-fold subdivision, based on the most marked differences in lithology, correlates, at least in the main, with the three-fold subdivision, with Benton, Niobrara, and Pierre, of the type region of the upper Missouri country.

The Pierre formation of this description was first named Papagallos by Cummins and soon after called Mendez by Jeffreys. The type locality of the latter term is Mendez Station on the Tampico-San Luis Potosi Railway where the upper strata of terra-cotta color (pink or red) crop out. There has been a tendency among some of the geologists in the Tampico region to restrict the term Mendez to these upper strata of the writer's Pierre and this action is to be commended.

The Colorado group (Benton and Niobrara) of this part of Mexico was originally named the San Juan by Cummins and the San Felipe by Jeffreys. Later the term Tamasopo came into general use for a thick

limestone believed to underlie the Colorado group, but still later work, both by actually tracing the beds and by obtaining definite fossil evidence, has proved the Tamasopo in its type locality in Tamasopo Cañon to be a pure solid limestone facies of the Colorado group. If the term Tamasopo is worthy of retention it is merely as a facies term.

It is a difficult matter to assign definite thicknesses to the different Upper Cretaceous formations underlying the Panuco field. Variations in thickness and possible explanations for such will be considered more fully in the section of this work devoted to structure. It will be sufficient for the present to give the more normal thicknesses in wells of the East Coast Oil Company in the Panuco section proper. The thickness of the Pierre here ranges from 1,040 to 1,640 feet, and of the Colorado group from 280 to 425 feet, with the more common thickness of 320 to 330 feet. The thickness assigned to the Niobrara is approximately 130 feet.

PIERRE BENTONITIC MARL

An examination of core samples from a section of the Pierre 1,150 feet in thickness shows that formation to be remarkably homogeneous. Other well samples and outcrop studies verify this. The material is marl composed of foraminiferal remains with a minor percentage of finely crystallized calcite and a large amount of tuffaceous material. The latter is present in every sample as a residue after dissolving out the calcareous matter with dilute hydrochloric acid. There are zones which contain much biotite in brown to blackish-colored cleavage flakes with jagged edges. The tuffaceous residue examined under the microscope is seen to be a very fine, flocculent, isotropic, glassy substance with markedly linear shape. It resembles palagonite except that it is lighter in color. The substance is really bentonite and appears exactly the same as the more or less pure bentonite interbedded with marls throughout the section. The purer bentonites are generally dirty light gray in color, but some are greenish, reddish, or purplish. All of the purer bentonite has the characteristic unctuous appearance. Some of it is spotted, in which case the original volcanic tuff is probably less completely altered. Small rounded concretionary pellets of powdery calcium carbonate are found in some of the beds and all the bentonite contains some calcareous material. There are also beds of relatively unaltered white volcanic ash. The original tuff must have formed a large part of the whole formation, certainly not less than one-fourth and possibly one-half of it.

The acidic composition of the volcanic tuff is indicated by the light shades of color of both altered and unaltered material. The real composition of the volcanic ash is demonstrated by a sample from a depth of 1,220 feet (745 feet above the top of the Washita) from East Coast well M-27, Laguna de la Milpa. This consists of grains of glassy sanidine, probably with some acidic plagioclase, quartz, and flakes of biotite in a matrix of milky white bentonitic substance. The ash therefore is rhyolitic. The quartz, feldspar, and mica have very regular angular surfaces and are fairly coarse in texture. This shows crystallization already well marked in the viscous magma at the time of the outburst and since the grains are not in the least waterworn, the explosion occurred near by and was probably submarine. There are also the same minerals present in the same condition in Corona No. 1, Topila field, at a horizon near the top of the Pierre.

A few small nodules of black oxide of manganese are found. A careful search in the core samples failed to show a single mineral particle of terrigenous detrital origin.

The top member of the formation as here delimited is of the color of lightly burned terra-cotta tile. In the Panuco section proper this member is logged as being from 20 to 100 feet in thickness, but is probably from 40 to 50 feet thick. This member thickens northward. A second member of the same color is logged lower down in several wells and likewise a third member at a horizon about 400 feet above the base of the formation. The first member appears to be persistent throughout the field, but the other two are not and they may be nothing more than local admixtures of reddish bentonite.

The remainder of the marl is gray to greenish-gray. The lower part is generally the more consolidated.

The Pierre carries a plentiful foraminiferal fauna. The foraminifers in the reddish upper zone are better preserved, larger, and probably more numerous than elsewhere. *Inoceramus* cf. *I. Vanuxemi* has been found in a core from the lower Pierre in one of the East Coast wells. The lower part of the formation drills more slowly than the rest. When this more consolidated portion is reached the formation is generally logged as "lime shells," and the top of these "lime shells" taken to be the top of the San Felipe. Continuous core samples, however, show that such "shells" or interbedded layers of limestone do not exist. The core samples also show that there is no bedding or lamination in the entire formation aside from the upper and lower surfaces of the more purely bentonitic interbeds.

There is generally from 10 to 60 feet of green and gray bentonite at the base of the Pierre.

NIOBRARA BENTONITIC CHALKY LIMESTONE

The Niobrara is a light green, foraminiferal, chalky, imperfectly consolidated limestone with several interbeds of bentonite which are prevalently purplish, reddish, or greenish. The calcareous matter is not pure, but intermixed with bentonitic tuff. The texture is prevalently fine-grained, but part of the rock exhibits fairly large crystal faces of calcite. Thin shells of fine-grained whitish or pinkish purer calcareous material are rather plentiful in drilling samples. These appear to be thin seams bounding the bentonitic layers and coating the bedding planes of limestone.

W. A. Baker, Jr., divides the Niobrara section of the entire northern fields from top to base as follows:

(a) 30 to 60 feet of green, largely fine-grained, brittle-fracturing, rather dense light green chalky limestone, in cores well stratified in 2- to 6- foot beds separated by 2- to 10-inch beds of green and dark gray marls, bentonitic marls, a mixture of white, green, pink and lilac-colored calcite and tuff. Locally some of the tuff is silicified into a dense, hard, brittle porcellaneous material.

(b) 100 to 240 feet of green limestone as in (a) with a few interbeds, 5 to 10 feet thick, of very light gray limestone, with other interbeds as in (a). In addition, there are layers, 2 to 18 inches thick, of white tuff.

(c) 20 to 60 feet of green limestone, with thin interbeds of light and dark gray limestone, marl, and bentonite.

BENTONITIC LIMESTONE AND INTERBEDDED BITUMINOUS LAMINATED STRATA OF THE BENTON

The most marked lithologic distinction between the Benton and the Niobrara is the presence in the former of thin interbeds of dark blue-gray to black laminated foraminiferal and very bituminous somewhat altered volcanic tuff. These tuffs are consolidated in greater degree than the tuffs in the higher formations. The relative percentage of the thinly laminated strata increases rather gradually from the top toward the bottom of the formation; the total amount is from one-eighth to one-fifth of the total thickness. The lower 30 to 85 feet contains interbeds of darker color.

The limestones of the Benton are denser than those of the Niobrara. In color they range from dark shades of gray to very light gray or gray-

ish-white through the lower 50 feet. The limestone contains a notable admixture of tuff and is also very foraminiferal.

The lower 50 feet of the Benton in the Panuco section proper contains a small amount of nodular dull brownish-black chert. This chert is found through an interval of approximately 100 feet in the Topila section. There is also a dove-colored or light gray dull chert found approximately 30 feet above the base of the Benton in Panuco proper. Near this in the section is also a light gray very dense and fine-grained silicious limestone, about 25 or 30 feet above the base. Very small botryoidal masses of a radiating fibrous bluish-white mineral insoluble in hydrochloric acid are found in many places at the base of the Benton.

The lowermost beds of Benton tuff are more compact in texture than somewhat similar beds above and are a bright and deep green. This color is caused by chloritization, the chlorite probably derived from altered biotite.

The basal Benton stratum is noteworthy as being the oldest[1] appearance of tuff in the Cretaceous deposits, and also as affording an indication of the manner in which the deposition of volcanic ash began in a sea bottom where calcareous oozes were accumulating. The rock is finely and imperfectly laminated and contains a high percentage of limestone. The ash is in small ball-like masses flattened in the plane of the laminations. These balls are of various colors: white, light gray, dark gray, and dull green. Under the microscope the matrix is seen to be calcite and the balls themselves to be altered phases of bentonitic tuff.

LOWER CRETACEOUS LIMESTONE

Our knowledge of the Lower Cretaceous of the Panuco section is only fragmentary since there are no continuous core samples.

There is no evidence of an unconformity between the Washita and the Benton either in the oil fields or in outcrop sections in the mountains. There is a perfectly gradational sequence in the succession; some of the lower Benton limestones are distinguishable only with difficulty from those of the upper Washita, the main distinction consisting in the slightly darker color of the former. Some of the limestones in the lower 50 feet of the Benton have the same hackly and conchoidal fracture and are substantially as brittle and densely fine-grained as is the upper Washita limestone. The chert in the upper Washita is, however, either dark smoky color and translucent or milky white,

[1] D. A. Powell, however, reports a stratum of bentonite in the upper 100 feet of the Washita in one of the La Aguada wells.

almost transparent, and nearly all of it shows a shining luster. A little lower down the chert becomes dark brown to black and has a shining luster. In continuous core samples there is no difficulty in distinguishing the contact between Benton and Washita since volcanic tuff is absent from the latter, but in standard or rotary-drilling samples the bentonite higher in the section is continually expanding and slaking upon becoming moistened and thereupon falls into lower levels of the hole.

The uppermost Washita limestone is extremely fine-grained and dense. It fractures into smooth-surfaced fragments nearly as sharp and angular as those of glass or flint. It has much the aspect of the very finest porcelain. The color is creamy white. This rock is somewhat more porous and without its porcellaneous appearance and characteristic brittle fracture in the portion of highest structure on the Ingenio lease, where it is presumed to have undergone some alteration.

The limestone changes to light brownish-gray, becomes less dense, and breaks with a rough-surfaced fracture about 40 feet below the top of the Washita. A section of the rock from 65 feet below the top shows the limestone to be very fine, crystalline, almost amorphous, with the exception that foraminiferal skeletons are filled with transparent crystalline calcite.

Few other details of the Washita succession of Panuco are now available and it will be necessary to give a brief description of the section exposed in the Sierra de Tamaulipas, which has been studied in some detail by E. H. Sellards. There the upper 138 feet, representing very probably the Buda and Del Rio of the Texas section, is relatively thin-bedded and characterized in particular by irregular wavy bedding and by much black chert. The chert seldom makes up entire layers, but rather is included within the limestone. The flint shows also a tendency to nodular development, the nodules being either disconnected or connected in irregular layers; at the base there is gradation through some dark-colored layers into the lighter-colored limestone of the Georgetown.

The Georgetown limestone in the Sierra de Tamaulipas is 305 feet thick. It is creamy-white, close-textured, heavy-bedded limestone with many stylolites parallel to the bedding. It contains much flint, either black or light in color. Some of the flint is colorless and glassy, and contains radiolarians; there is also milky-white flint.

A core from East Coast well 206, Halcon, taken at 396 feet below the top of the Washita, shows a light cream-colored very dense and

fine-grained porcelain-like limestone breaking with a sharp sub-conchoidal fracture. In thin section the texture of this rock is seen to be extremely fine, but with foraminiferal skeletons filled with more coarsely crystalline calcite. The core shows also a thin layer of light brown-gray, partially laminated limestone which is less dense though very fine-grained.

The total thickness of the Washita in the Sierra de Tamaulipas is 444 feet. In the East Coast Panuco leases its thickness is 480 feet. In other parts of the Panuco field the total thickness is stated to be generally 580 feet; the increase in thickness is probably caused by crumpling.

The Washita of the Panuco field belongs to a facies which might be given the name of Tamaulipas, although the term Tamaulipas or its correlative, Victoria, is applied by some geologists to the whole section of Lower Cretaceous of northeastern Mexico. The same facies of Washita occurring in Panuco is found in the Sierra de Tamaulipas, the easternmost front ranges west of Ciudad Victoria, and the diamond bore holes on the Naranjo Hacienda. A different facies, which can be termed the El Abra, is found in the easternmost front ranges west and northwest of Panuco, and in the southern oil fields. The El Abra facies of the Georgetown is a creamy white, shallow-water, heavy-bedded reef limestone, largely composed of rolled fossils, the most plentiful of which are rudistids and chamids, succeeded by a light gray limestone nearly without bedding planes and very largely composed of large miliolid foraminifers.

A shale, highly calcareous, of dark brown to black color, very bituminous and interbedded with dark brown limestone, underlies the Georgetown. Dull dark brown chert is plentiful. The thickness is unknown since it probably follows down the bore hole into samples taken from beneath its base, but it is probably between 25 and 50 feet thick. This member is the lowest rock yet found exposed in the Sierra de Tamaulipas. It there carries some poorly preserved ammonites and 50 feet of it is seen with its base not exposed. It is probably the equivalent of the Kiamitia of northeastern Texas.

Very little is known of the lower strata of the Cretaceous which appear to be entirely of limestone. Cores taken 1,100 feet and 1,270 feet below the top of the Washita are fine-grained limestones with many foraminifers replaced with calcite. A core sample from 1,510 feet beneath the top of the Washita consists of a very light gray, dense, fine-grained limestone of lithographic texture, containing calcitized foraminifers. The limestone has changed to a dark gray and become cherty

at a depth of 52 feet farther down and a core sample 250 feet still lower is of a dark gray fine-grained limestone with some interbeds of black shale. The strata occurring at a depth greater than 1,570 feet beneath the top of the Washita may be Jurassic or older.

UPPER JURASSIC

The Upper Jurassic section of northeastern Mexico is best known from outcrops in the cordillera from Monterrey southward to south of the latitude of Tampico. There appears to be Jurassic older than the upper division in the mountains southwest and south-southwest of the Tampico district. The Upper Jurassic in the mountains north of the latitude of Tampico rests upon Red beds and gypsum. Extensive gypsum deposits so greatly crumpled under planes of overthrusting that they locally resemble salt domes greatly obscure the relationships of the Jurassic with older strata. The Red beds are cut by quartz veins and apparently more greatly deformed than overlying beds. This would indicate angular unconformity between Upper Jurassic and older beds. The thrust movements have, however, introduced complications and a large amount of careful work on the mountain stratigraphy must yet be done before we can be sure of the exact stratigraphy of strata older than the Kimmeridge.

In the Catorce mining district, San Luis Potosi state, a normal succession is present. There a series of partly metamorphosed Red beds injected with veins, stringers, and lenses of quartz rests on an older basement complex. The Red beds are unconformably overlain by unmetamorphosed sedimentary rocks beginning as low as the Oxford or lower stage of the Upper Jurassic and grading conformably upward into Cretaceous. In the mountains east of Catorce the lower 1,500 feet of the Upper Jurassic has not been found although it is represented by strata in the vicinity of Monterrey. Either it was never deposited in western Tamaulipas or southern Nuevo Leon or it has been thrust out of the sections heretofore studied. So far as known, Jurassic deposition began with the Kimmeridge in the region nearer Tampico and continued without break through the Portland up into the Cretaceous.

The Kimmeridge is a very distinctive horizon of black and brown bituminous phosphatic and marly shales with interbedded dark limestones and a minor amount of dark chert. Various ammonites of the *Idoceras* assemblage and fish remains are very common although molluscs and other fossils are also found. There is more pyrite and marcasite than in the Cretaceous. Dark brownish-black phosphatic nodules

and concretions containing ammonites and *Halobia* (*Monotis*) are fairly common. There are some thin beds resembling Fuller's earth which may possibly prove to be bentonite.

The black color of the shales is caused by bituminous and carbonaceous matter. The shales upon being tested with ether show the presence of much oil.

The Portland is lithologically a transition zone between the shaly Kimmeridge and the Cretaceous limestones. There is some shale interbedded with limestones at the base passing up into thin-bedded flaggy limestones with many flattened ammonites at the top. Dark chert is present in many nodules and thin layers. The color is dark gray to black at the base, gradually becoming lighter gray in upward succession.

The thickness of the Kimmeridge and Portland is at least 1,400 feet in the Catorce section. It thins eastward but is probably at least 250 or 300 feet thick in the Panuco section although its total thickness is there unknown. The thickness may be greater in the mountains southwest of Tampico.

The Kimmeridge is one of the most widespread formations in Mexico, known from the Malone Mountains of southwestern Trans-Pecos Texas to the Isthmus of Tehuantepec.

PRE-JURASSIC SEDIMENTARY ROCKS

Coarse-grained light-colored cavernous oölitic dolomite and an underlying limestone, the age and stratigraphic relations of which are unknown, overlie the Red beds in the Altamira and Panuco sections.

The only information we have on the older sediments is from exposures in the eastern front range a short distance northwest of Ciudad Victoria, capital of the State of Tamaulipas. The Red beds there probably unconformably overlie sandstones of Keokuk Mississippian age and dark, possibly bituminous, shales, with some thin interbedded layers of quartzose grits ("mortar beds") containing *Fusilina*, certainly the equivalent of the Cieneguita-Alta beds of Presidio County, Texas, which the writer's recent investigations have shown to be without question very early Permian.

Structural relationships are complex in the eastern front range and it is possible other sedimentary rocks will be found in the mountain area between Cuidad Victoria and Monterrey. Basement complex metamorphic and crystalline rocks are exposed at several localities in the mountains of San Luis Potosi, Tamaulipas, and southern Nuevo Leon, notably at Catorce, El Huichichal-Joya Verde, Miquihuana-Bustamante, and La Presa or Peregrina Cañon.

DEPOSITIONAL HISTORY OF THE CRETACEOUS

No circumscribed area can be thoroughly understood in history and structure without a thorough study of the surrounding territory. This is more particularly true when we consider a district in which the bed rocks can not be studied in surface exposures. The explorations of 1924-26 in the southern half of the state of Tamaulipas and the eastern part of the state of San Luis Potosi, although they have been both hurried and fragmentary, have thrown a flood of light upon many formerly very obscure Panuco problems. Therefore, no apology is necessary in considering historical and structural problems from a regional standpoint. Since satisfactory surface exposures are relatively far distant from the Panuco field, it is prudent not to stress too strongly the exact equivalence of events as determinable in the regions of outcrop. This is particularly uncertain for the times antedating the Cretaceous; the Cretaceous of northeastern Mexico furnishes, however, a record of large scale and surprisingly uniform depositional history, which, once known, simplifies very greatly our more localized tasks in the Panuco field.

A continuous cycle of marine deposition began in northeastern Mexico in the lower part of the Upper Jurassic and lasted until close to the end of the Upper Cretaceous. The tops of some of the highest anticlinal areas in the front ranges west of Ciudad Victoria may have persisted as islands in the sea until as late as the Hauterevian-Valanginian stage of the pre-Trinity Lower Cretaceous.[1] These various deposits of the Upper Jurassic and Lower Cretaceous progressively overlap the Basement Complex, upper Paleozoic, and possible lower Mesozoic rocks, indicating extensive erosion of the region before the Upper Jurassic. Rocks of Upper Jurassic and pre-Fredericksburg Cretaceous are probably entirely concealed in the Sierra de Tamaulipas. In the Altamira deep test a thin glauconitic zone separates Upper Jurassic from Lower Cretaceous, but there was no unconformity or at the most a slight one, between the Jurassic and the Cretaceous since Hauterevian-Valanginian fossils were found above the glauconitic layer and fossils of the Portland, or uppermost stage of the Jurassic, below it.

The depositional cycle began and ended with shallow-water littoral deposits. In the Catorce mining district in the state of San Luis Potosi, the cycle began with conglomerates which successively grade upward into sandstones, shales, marls, and limestones until the massive lime-

[1]These are in an area of extensive thrusting which may have sheared out the Jurassic rocks.

stone of the Oxfordian(?) is reached. East of Catorce, in the country centering around Aramberri and Las Virgenes, in the Nuevo Leon-Tamaulipas border area, the basal deposits of the cycle have not been found, but extensive deposits of gypsum underlie the Kimmeridge beds. The Kimmeridge throughout the eastern cordillera is mainly composed of bituminous and phosphatic shales. In the Portland the shales grade upward into thin flaggy-bedded limestones which pass over into the lowermost Cretaceous purer and heavier-bedded limestones. Deposition of pure limestones then continued until the close of the Niobrara. Land-derived detritus is not found again until Fox Hills time, with the exception that littoral pack sands were deposited in the Pierre of the Puerto-Villar locality along the Tampico-San Luis Potosi Railway at a distance of 150 miles west of Panuco.

The Niobrara and Benton of the Panuco area, of the Sierra de Tamaulipas exposures, and of the easternmost front ranges of the main cordillera pass westward into thicker deposits of pure limestone. The volcanic tuff, which makes up so large a percentage of Benton, Niobrara, and Pierre of the Sierra de Tamaulipas anticline, gradually lessens in amount westward into the cordillera and a short distance west of the outermost front ranges probably entirely ceases. Therefore, the volcanic activity in the Upper Cretaceous was either in the region of the Sierra de Tamaulipas or farther east.

With very minor exceptions the Cretaceous deposits laid down before Fox Hills time were deposited in clear water far from the shorelines of the Cretaceous sea. Detrital material is lacking from this sequence.

The most extraordinary characteristic of the Cretaceous section between the lower limit of the Hauterevian-Valanginian stage and the lower limit of the Fox Hills is the great scarcity in fossils other than the very plentiful foraminifers. This is conspicuously different from other Paleozoic and Mesozoic pure limestone strata of North America. As the Cretaceous limestones of this region are not dark colored and do not contain more than the average amount of pyrite, it does not appear probable that the water was of so foul a nature that the larger organisms could not live in it. This northeastern Mexican pure foraminiferal limestone succession is comparable to the purer diatomaceous phases of the Monterrey group of California, since the ordinary invertebrate fossils are conspicuously rare in both. The evidence so far indicates that the limestones were deposited in intermediate depths of the ocean in waters too deep for blue clay deposits and yet shallower than the abysmal

"deeps." The limestones appear to be *Globigerina* and other foraminiferal oozes deposited in places in water as much as 5,000 feet deep. In such depths of water Sir John Murray found that *Radiolaria* are scarce because their silica is dissolved in excess of lime. It is possible that the silica of the dissolved *Radiolaria* may form the silicious and chert content of the limestones.

The Pierre and lower Velasco sediments are still in the form of partly consolidated foraminiferal oozes, but the lower strata have been consolidated into ordinary limestones.

IGNEOUS ROCKS

Intrusive basalts reach the surface in the Ebano section and have been encountered there in several wells. Vesicular basalt outcrops in the Tamismolon Hacienda, about 10 miles south-southwest of the town of Panuco, and basalt reaches the surface in the vicinity of Tamante Hill about 10 miles south of Panuco. Basaltic intrusives and extrusives are common in this part of Mexico.

Olivine-basalt was encountered at depths from the base of the alluvium to at least 600 feet in seven wells in the West Maguabes Hacienda of the Panuco section proper.

The San Manuel deep test, situated near the top of the main Panuco anticline, has encountered to date four intrusive rocks. The uppermost, at a depth of 2,170 feet, has not been examined by the writer. A fairly coarse-grained diorite with soda-lime feldspar and hornblende, was found at depths of 3,145 to 3,200 feet. A basalt with very fine-grained ground-mass probably occurs at 3,380 feet. A little flesh-colored orthoclase and considerable quartz occurs from the 3,400-foot sample downward and there is sphene from the 3,430-foot sample downward. Transparent angular fragments of quartz are found in all samples from this well below a depth of 3,340 feet, but since a rotary drill was used and the slush pit not cleaned during drilling samples are very much mixed. Biotite-hornblende granite occurs in the samples between 3,570 and 3,630 feet. The main minerals of the hornblende-granite are unaltered flesh-colored orthoclase, clear transparent quartz with some crystal faces, biotite, and hornblende, some of the latter being attached to the orthoclase. Accessory minerals are magnetite, sphene (titanite), and zircon. It is impossible to tell from the rotary samples whether more than one granite mass was penetrated.

There is definite evidence that the basaltic eruptions began as early as the upper Oligocene or early Miocene and continued until the Pleis-

tocene. The granite may have been intruded as early as the Upper Cretaceous since the volcanic tuff in the Upper Cretaceous is of the same composition. Diorite and syenite intrude the Upper Cretaceous sediments of the Sierra de Tamaulipas. Igneous rocks ranging in composition from acid to basic are widespread in the Sierra de Tamaulipas, but the common nepheline-syenites of the mountain outcrops have not yet been found in the Panuco field.

A conglomerate largely composed of unworn and undecomposed crystals of sanidine is found in the Pitahaya Hill, fifteen miles south-southwest of the town of Panuco. This conglomerate dips 12° SE. It forms part of a marine Tertiary section the exact age of which is unknown, but is probably Upper Oligocene or Lower Miocene. The plentiful sanidine, very little waterworn and practically undecomposed, indicates a near-by source from an igneous rock which was being eroded at the time the conglomerate was deposited. This igneous rock was erupted before the middle of the Cenozoic.

We can, therefore, say definitely that the igneous activity in the Panuco area began in the oldest Benton and may have continued until the Pleistocene. The volcanic ash in the Upper Cretaceous must have been altered to bentonite before or during deposition, thus being formed in the same way as palagonite.

ORE DEPOSITS AND CONTACT METAMORPHISM

A core sample from a depth of 3,550 feet in the San Manuel deep test is of a limestone country rock, dark gray and dove-colored, spotted and fine-grained. This upon being treated with dilute hydrochloric acid leaves a spongy skeleton of amorphous silica. There are some thin beds of black calcareous shale. The limestone in thin section shows many *Foraminifera*, *Radiolaria*, sponge spicules, and fragments of minute molluscan shells. It is extensively cut by veinlets of calcite. There has been extensive addition of chalcopyrite and pyrite, both primary ore minerals, which occur in large well crystallized masses. Chalcopyrite also occurs in the sample from 3,470 feet in the same well.

Chalcopyrite is present in several wells drilled on faults in the East Coast Ingenio and Laguna de la Milpa leases. In one of these secondary blue-green chrysocolla encloses chalcopyrite and the mineral chrysocolla is found in other wells in the faulted zones. Samples from the depth of 3,460 feet and vicinity in the San Manuel deep test contain a high concentration of somewhat coarsely crystalline magnetite. It is probable that a deposit of magnetite is present at approximately 3,460

feet although the possibility of the bit and drill stem having for some reason become demagnetized and releasing a concentration of magnetite from the intrusive rocks must be taken into consideration. Characteristic contact metamorphic minerals are probable grossularite-garnet at about 3,400 feet and the magnetite just mentioned. In the pure Cretaceous limestones metamorphism is generally by marmorization, garnetization, or silicification.

STRUCTURE

The Panuco section proper and Topila are the only parts of the Panuco field in which the structure has been studied by the writer. No attempt will be made in this paper to consider structural details elsewhere.

The top of the Washita is the only safe structural datum plane. Fully half the wells in the Panuco and Topila sections were drilled before accurate records were kept and it is not possible to obtain accurate structural and stratigraphic data of more than a very few of the older wells. The structure is so extraordinarily irregular that it is unsafe to interpolate contours between wells with accurate structural data in many places, even where such wells are relatively close together. Many wells were not drilled so deep as the top of the Washita and reveal only uncertain facts of structure.

The larger structural features of the Panuco section proper comprise the main Panuco anticline or "high," which is flanked on the east by the Tampuche syncline and on the west by the Tanchiquin syncline. The structural relief is fairly great, amounting to more than 850 feet in a distance of 2¾ miles between the highest known point on the Panuco anticline and the lowest known point in the Tampuche syncline and to 700 feet between the highest known point on the Panuco anticline and a point 3½ miles west in the Tanchicuin syncline. It is to be noticed that all the present productive sections are confined to the summit of a much greater anticline. The Tampuche syncline bifurcates, in its northern part, the western branch paralleling in strike the Panuco anticline and a northeastern branch forming the northwest side of the Topila field.

The northern half of the main Panuco anticline begins a mile northwest of the center of the town of Panuco, and extends with an axial direction of N. 15° W. for a distance of 3 miles into southern Cacalilao. There is a pronounced terrace about 1 mile in width lying just east of the axis and extending parallel to the axis for the northern 2 miles. The terrace is bounded on the east by an abrupt, probably faulted, down-

plunge of 650 feet in one mile striking nearly north. This is probably the greatest amount of dip in the entire section. This dip extends to the trough of the western bifurcation of the Tampuche syncline. There are two local domes at either end of the north part of the anticline which are possibly formed by igneous intrusion; the intrusions found in the San Manuel deep test underlie the summit of the southern dome. The southern dome is bounded on the south-southeast by the San Manuel fault, traced for three-fourths of a mile, with a direction of approximately N. 60° E.

The southern part of the Panuco anticline is much more complicated. It is somewhat west of the northern part and is separated from it by a low saddle. In the first 1¼ miles the axis strikes N. 30° W., but in the middle of the Ingenio lease it turns abruptly at right angles and extends west-southwest for a mile. The complications are caused by ten or more sub-parallel faults striking from nearly due northeast to N. 65° E. The vertical displacements of the faults have a wide range, with a known maximum of 160 feet; a belt less than half a mile wide in Zurita, Peralta, Potrero del Zacate, and southeastern Ingenio is a faulted zone having at least six sub-parallel faults. Nearly all the wells in this belt were drilled before accurate records were kept and the structural details will probably never be known. The San Manuel fault zone crosses the center of the southern part of the Panuco anticline and dies out on its western flank. It is now almost certain that more than one fault, in addition to the ten already mentioned, bound the southern part of the anticline on the south-southeast and that the north-northwest boundary is either a fault or a steep downplunge. The dip on the west flank is much more gentle than on the east.

The evidence for faulting is plentiful and conclusive. Open cavities have been found in drilling and many of the fragments blown out of wells have open spaces lined with calcite crystals. Studies of drilling samples show displacements. Closely contiguous bore holes reach the top of the Washita at widely different depths. The occurrence of the primary ore mineral, chalcopyrite, in wells along displacements indicates veins on faults. Large producing wells are situated in faulted or creviced zones since wells drilled in the solid, unfractured limestone do not get commercially profitable production. The occurrence of the oil at no definite stratigraphic horizon, but from the top to the base of the entire Cretaceous, also shows that the oil is accumulated in open spaces, either fractures or crevices in the elsewhere nonproductive strata. It is very much the exception for closely offset wells to derive their production from exactly the same stratigraphic level.

The open spaces in which the oil, water, or gas has accumulated in the Panuco field are caused by (1) faulting, (2) jointing,—fracture without appreciable displacement, and (3) solution. Fractures caused by settling as a consequence of solution cannot be distinguished from faults and joints.

Some of the faults reach the surface of the bedrock. Several in the Tamesi valley are indicated by lines of seepages. Many of the faults, however, do not reach the surface of the bedrock. The upper formations, the Pierre and Velasco, are incompetent and yield by partial "flow" (crumpling or acute local folding) to movements causing displacements of the underlying more brittle rocks. It seems probable that fractures are more prevalent in the lower parts of the limestone, since any well if carried deep enough will encounter either oil or salt water, but not in any definite stratigraphic horizon. Several wells have been drilled to depths 500 or more feet below the top of the Washita without encountering either salt water or oil in profitable amount.

Fractures in the Panuco field have at least the following possible causes: (1) tensional cracks formed as a consequence of doming irrespective of its origin, (2) faults produced by earth-folding movements, (3) displacements produced directly by movements of igneous magma, (4) expansion by heating and contraction by cooling, and by dolomitization, and expansion and contraction by other metamorphic action such as addition or subtraction of mineral matter, and (5) cavities formed by solution of underground water and by settlement after solution.

It has been known for some years that wherever contours drawn on the upper surface of the Washita are closer spaced than the average, or where they abruptly change direction, fracturing is probable; consequently, profitable production may be sought with greater chances of success. The limestone below the top of the Benton is so brittle that it yields by shattering in the zones where the rate of dip has increased under deformative influences.

The Tanchicuin syncline enters the Panuco section from the west flank of the Panuco anticline, forming a broad embayment between the north-northwest flank of the southern part, the west flank of the northern part, and the south flank of the area of high structure of western Cacalilao. Five minor synclines plunge westward into the main syncline from the west flank of the Panuco anticline. The plunge of the trough is in general southwestward from the north end of the northern domal area of the north end of the main Panuco anticline. The Halcon fault

of the east flank of the syncline is at least one-half mile long and strikes N. 28° 12′ E.

The Tampuche syncline separates the Panuco anticline from the Paciencia y Aguacate dome. Its west flank is the steeper. The plunge is to the south. The direction of the branch which plunges southwestward from the northwest side of the Paciencia y Aguacate dome, if continued, would reach the area of closest faulting on the Ingenio and Potrero del Zacate leases on the southeast flank of the southern part of the Panuco anticline. It is noteworthy that the intermediate zone on both flanks and in the trough of the Tampuche syncline has been a fairly continuous belt of high production. The olivine-basalt (limburgite) intrusions of west Maguabes are in the trough of the Tampuche syncline.

Topila is a domal uplift, irregular in outline and in detail of structure. Its point of highest known structure, on the Paciencia y Aguacate dome, where the top of the Washita is 2,145 feet beneath the surface, is 400 feet lower than the point of highest known structure of the Panuco anticline. A terrace of about one mile in width and three miles in length from east to west borders the southeast flank of the main dome. The dome is apparently flanked on the south by fairly steep dips, but there has not been enough development to make this certain. The summit area of the dome is fairly flat structurally over an area of about 7 square miles and probably for this reason fracturing does not seem to be as great as in the Panuco section. Relatively little development has been done in Topila, hence the structural conditions are very imperfectly known, especially on the northeast and south flanks. The faults now known appear to radiate imperfectly from the center of the Paciencia y Aguacate dome.

We will now consider the nature and cause of the most puzzling phenomenon of the greatly variant thicknesses of the Upper Cretaceous formations. Tables I and II, showing thicknesses in East Coast and other wells, will serve to place some of the facts before the reader.

It will be apparent from these lists that the geologist cannot safely use any structural datum plane above the top of the Washita. Neither the study of *Foraminifera* nor lithologic correlations of the upper formations will afford accurate data on the structure of the top surface of the Washita.

We can safely eliminate as possible causes of the variations in thickness, difference in rate of dip, inequalities of sea bottom, unconformity, variations in thickness of volcanic tuff, and current action, as one formation may be thick and the other thin, or both may be either

TABLE I

FORMATIONAL THICKNESSES IN FEET, PANUCO AND TOPILA

Well Number	Pierre: Top Red Mendez To Top Green Lime	Colorado Group: Top Green Lime To Top Washita
INGENIO:		
420	1080?	340
422	....	320 or more
423	1210?	380?
425	1165?	250?
426	....	330
427	....	265?
429	....	320
430	1150?	320
431	....	320
432	1040	390 (faulted)
433	1160	400 (faulted)
434	1120	330
436	1180	320
437	1120	330
438	1170	320
439	1190	280
443	1120	325
446	1280	320
447	1160	...
450	1120	320
451	1200	280
452	1280	323
453	1140	330
457	1170	230
D. A. WILLIAMSON, K. TAMPUCHE TRANSCONTINENTAL-ARTEAGA, TAMPUCHE HALCON:		505 370
206	1316	304
207	1270	...
211	1320	300
212	1320	300
213	1260	335
214	1290	340
216	1400	330
217	1200	320
223	1190	320
228	1215	325
229	1170	330
LAGUNA DE LA MILPA:		
M-13	1190	...
M-16	1140	365
M-20	1250	380
M-21	1210	348
M-22	1260	340
M-23	1180	370
M-25	....	335
M-26	1060	330
M-28	1190	315
M-29	1180	403
M-34	1220	330

TABLE 1—Continued

Well Number	Pierre: Top Red Mendez To Top Green Lime	Colorado Group Top Green Lime To Top Washita
M-38	1210	300
M-39	1130	330
M-40	1080	335
M-44	1130	350
M-47	1150	335
M-52	1310	...
M-53	1270	360
TANANTORO 12:	....	320
CHIJOLES UNO,		
NATIONAL 15:	1255	260
POTRERILLOS:		
M-14	....	243-263
M-15	1240	425
424	1175	...
M-42	1270	327 or more
MANZANAL LEASE:		
M-12	....	258-288
POTRERO RECREO:		
M-17	1220	370
M-19	1325	300
M-43	1600	390
ESTERO GRANDE:		
M-18	1280	407
TAMBOYOCHE:		
(Topila)		
P-3	1310	...
P-4	1325	310
506-A	1270	395
508	1500	310
508-A	....	302
509	1300	397
PALANGANA:		
304	1220	225
305	1290	255
306	1220	315
P-7	1240	220
P-8	1230	280
P-10	1290	360
306	1223	355
CON MEX 6	1240	240
CREDITO PETROLERO	1197	254
VEGA TEXAS	....	220
AZUARA 3		
TAMANTE:		
T-1	1280	200
T-2	1205	245
T-4	....	180(faulted)
Maximum	1600	505
Mimimum	1040	200

TABLE II

THICKNESSES FROM FORAMINIFERAL DETERMINATIONS
By Esther Richards Applin

PANUCO AND TOPILA

Well No.	Quaternary and Recent	Velasco A	Velasco B	Pierre A	Pierre B	Pierre C	Total Pierre	Total S. Felipe*
POTRERO RECREO:								
M-17	170	170	220	240	200	420	860	835
LAGUNA DE LA MILPA:								
M-13	....	....	158	360–440	....	....	....	....
HALCON:								
206	180	80	190 or less	150	250	370	770	910
207	....	....	....	....	....	400 or more	....	....
208	220	380	....	....	....	....	....	....
209	....	....	....	140 or more	180	200(?)	540(?)	....
212	160	120	160	240	140	490	870	920
TAMANTE:								
1	....	....	....	....	....	....	1000	640
PALANGANA:								
8	....	....	....	....	....	400 or more	....	690
TAMBOYOCHE:								
508	....	....	....	100 or more	590	195	885	710

*Mrs. Applin's San Felipe includes lower part of writer's Pierre.

thick or thin and the differences are very irregularly distributed in location. For example, in well M-15 the Colorado group is 425 feet thick and the Pierre 1,240 feet. In near-by wells the thickness is as shown in Table III.

The range of thickness in an area of less than a square mile in the Ingenio lease, excepting wells with evidence of faulting, is from 230 to 400 feet for the Colorado group and from 1,120 to 1,280 feet for the Pierre. In the Halcon lease, where the dip is low and more regular than ordinarily, the range is from 300 to 340 feet for the Colorado group and from 1,170 to 1,400 feet for the Pierre.

The wells were drilled with standard and rotary tools and we cannot adequately evaluate the range of thickness caused by drag near

TABLE III

FORMATIONAL THICKNESSES IN FEET

		Thickness Colorado Group	Thickness Pierre
M-12	1080 feet distant E.-NE.	288	....
M-19	2025 feet distant W.	300	1325
M-43	1050 feet distant N.-NW.	390	1600
M-42	1960 feet distant S.-SW.	327	1270
424	820 feet distant S.	....	1175
M-14	1540 feet distant S.-SE.	260	....

NOTE.—Top of the Washita lime is 15 feet and 30 feet respectively deeper in M-12 and M-14 than in M-15.

faults and slumped blocks or by settlement as an effect of solution or cooling of magmas. A greater amount of consolidation (increase in density) caused by increased downward pressure of a thicker rock section is not a satisfactory explanation since the Colorado group has a greater average thickness in the Tampuche syncline than in the anticlines. There is one factor which we cannot successfully eliminate, the driller.

However, there are available other lines of evidence, derived from a study of surface outcrops and diamond drill cores. The Pierre is extensively exposed on the axial portion of the Sierra de Tamaulipas anticline for many miles north of the Panuco section proper and the entire Upper Cretaceous section is exposed in a vast area of the great geosyncline between the Sierra de Tamaulipas and the front ranges of the main cordillera. The strata in these exposures are locally strongly crumpled and buckled. Faults with slickensided walls and calcite veins are by no means rare. Such crumpling and faulting are to be expected in the non-competent poorly consolidated Pierre and "Velasco" strata of the geosyncline since both downward flexure and extensive thrusting from the west are certain to cause them. Yet they would scarcely be predicated over the low, broad, gently deformed arch of the southern end of the Sierra of Tamaulipas anticline.

The Topila Hills are situated at the east edge of the oil-producing territory, that is to say, at the east foot of the broad arch forming the higher part of a much broader anticline. There is a steepening of dip in the Washita in the vicinity of the Topila Hills. These hills are composed of strata of the lower half of the Cenozoic thrown into narrow folds with medium angles of dip. It has been proved by drilling that

these folds are superficial and do not extend so far down as the Washita.

Strata of the first half of the Cenozoic are deformed into narrow very sharp folds in an area a short distance northwest of the town of Soto la Marina. This place is also well down on the east flank of the Sierra de Tamaulipas anticline. The thickness of the intensely folded strata ranges between 500 and 1,000 feet. Several of these folds with steep, vertical and even overturned dips and faulting are crossed in the distance of a mile. The dips flanking this area are not greater than 10 degrees and are nearly all eastward.

Itamex La Mula No. 20 well was drilled in the northeast part of the Topila field. The Benton strata in this well dip from 2 to 5 degrees but there is no apparent dip in the overlying Niobrara. International Naranjo No. 8 well, drilled with diamond core drill, is on the west flank of the geosyncline west of the Sierra de Tamaulipas and about 40 miles northwest of the town of Panuco. Local high dips and crumpling are shown by the cores through a section 275 feet thick with its top 50 feet below the top of the Washita, while both above and below the 275-foot zone the strata are virtually horizontal. Similar crumplings are shown in cores from La Aguada and no well yet continuously cored has failed to show local crumpling.

The buckling of the older Tertiary in narrow zones on the east flank of the Sierra de Tamaulipas anticline appears to have been caused by thrusting movements since no near-by laccoliths or other forms of large intrusions are known which might cause the shortening demonstrated in the zones of closer folding. The intra-formational zones of movement shown by crumpling and dips not found higher or lower in the vertical section—which are a common phenomenon in the eastern front ranges of the cordillera—are probably also caused by thrusting. The zone of disturbance which extends west-southwest from the northwestern margin of the Paciencia y Aguacate dome diagonally across the deeper part of the Tampuche syncline and across the southern part of the main Panuco anticline may have caused the shift to the westward of that part of the anticline and caused its fracturing into blocks along sub-parallel faults although these phenomena may have been caused by intrusion of igneous rock at lower levels. Finally, the widespread occurrence of the previously described types of crumplings in adjacent territory and their more probable origin by thrusting give the more plausible though perhaps not the only cause of the variations in thickness of Upper Cretaceous strata in the Panuco field.

There has been thrusting in the eastern front ranges of the Mexican cordillera on a scale not known to be surpassed elsewhere on the conti-

nent. In the mountain territory directly west of Panuco the commonest type of structure is that of double-recumbent fan-shaped folds in which heavy-bedded well-consolidated limestone 3,000 feet thick, which would be competent under almost every other tectonic action, has behaved like wax, becoming squeezed into the fan-folds to so great an extent that the upper surfaces of the limestone in adjacent folds almost meet and thousands of feet of Pierre and Fox Hills marls, shales, and sandstones, relatively non-competent strata, have been squeezed out of the intervening synclines. Farther east the dominant structural type becomes westward-dipping isoclines. Thrust-faulting is associated with both fan-folds and isoclines.

Farther north, northwest of Ciudad Victoria, there are successive overthrust sheets or "klippen" many miles in length, and with as much as 4 miles of determinable lateral displacement. These overthrusts are of the imbricated type of the Scottish Highlands or Alps. Eastward, they pass, north of Ciudad Victoria, into westward-dipping isoclinal structures although one of the greater overthrust sheets forms the great Chorrito escarpment at the very edge of the plains area of the geosyncline between the front ranges and Sierra de San Carlos.

Still farther north, south of Monterrey and Saltillo, the axial lines turn east-west, or nearly at right angles to their strike on the south and north and there is a relatively narrow province of closely-pressed fan-shaped folds.

North of Monterrey and Saltillo the Lower and Middle Cretaceous limestone forms extremely steep and narrow folds with broad intervening synclines of the less competent Upper Cretaceous. This type of structure is most probably caused by an extensive sliding of the Cretaceous strata over a relatively immobile basement.

In the Chihuahua-Texas border area, south of Sierra Blanca and Van Horn, Texas, the Cretaceous strata are several times repeated in overthrust blocks and isoclines with southwestward dips.

The overthrusting in the mountains is eastward. Still we know nothing that will successfully controvert the view that the thrusting movement was westward from the Gulf of Mexico toward the continental mass. There is also a possibility that there were simultaneous thrustings from opposite directions. It is the effects, not the causes, which now concern us. It is judged that the most probable explanation of the variations of thicknesses in the Upper Cretaceous of Panuco is thrusting movement. Whatever the direction or directions of the thrusts it is conceivable that the more superficial Upper Cretaceous strata, less

competent and resistant to deformative forces and more likely to yield by folding, crumpling, buckling, and partial "flowage" than by sharp, well-defined and large fault displacements both horizontal and vertical, have really so yielded, although the effects of the broad doming, solution, block-faulting with predominantly vertical displacements, and the varied effects of igneous intrusion can not be satisfactorily separated from effects of regional thrusting even so far as to be certain which of these causes was dominant. A movement of westward translation from the depositional geosyncline of the western Gulf of Mexico would be transmitted more uniformly and regularly through the deeper-lying and stronger rocks and there would be marked tendency for the weaker superficial beds to lag behind in such a movement and the resistance generated in the piling-up of the massifs on the eastern edge of the highlands on the west would cause local yielding in the weakly resistant upper strata. It is possible, indeed, that extensive overthrust sheets of alpine proportions with their roots in the eastern front ranges once covered the Panuco field and caused crumplings underneath the major thrust planes, but no remnants of such sheets are now known, although it must be remembered that there have been two fairly complete cycles of erosion in the country east of the cordillera since the greater earth movements ceased.

DATES OF DEFORMATION

Although the evidence for dating the two epochs of deformation is fairly satisfactory for the Sierra de Tamaulipas anticline, it will be necessary to utilize data at hand for entire northeastern Mexico in order to present the history in fairly complete manner.

The only indubitable evidence of unconformity within the Cretaceous is found on both east and west flanks of the major anticline of the easternmost front ranges for considerably more than 100 miles southeast and south of Gomez Farias and the upper end of Guayalejo Cañon where that stream leaves the Jamauve basin. This is the same line along which the deeper-water Tamaulipas limestone facies abruptly changes to the shallow-water El Abra reef facies. The localities given are from 90 to 120 miles northwest of the town of Panuco. In both localities the Pierre with a basal conglomerate lies upon eroded edges of the Washita. The conglomerate contains rolled, waterworn, and partially corroded rudistids of the Washita. There appears to be definite evidence of unconformity since brecciation caused by lateral movement could scarcely have occurred on the junction of the very competent

Washita limestone and the incompetent marls of the Pierre. The cordillera exhibits many zones of intra-formational brecciation within the competent limestone sequence, but such are to be expected in acute deformation. The zone of unconformity extends along the outer front range far southwest of Panuco, remnants of the San Felipe series being found locally beneath the Pierre.

The Georgetown strata in the El Abra Range, 45 miles west of Panuco town, are made up largely of rolled fossils and are succeeded by a limestone mainly composed of miliolid *Foraminifera*. The rolled fossils appear to have been deposited in shallow water; more likely they were piled up in reefs as the effect of currents. The fossils are predominantly reef-building rudistids and chamids.

The El Abra Range is the southern continuation of the great anticline between the Jamuave basin and the geosyncline east of the cordillera. It is probable that movements occurred along this line in the Cretaceous, a continuation of earlier movements shown in late Paleozoic or early Mesozoic folding.

The movements which brought to an end the late Jurassic-Cretaceous cycle of marine deposition are first apparent in clay and sand deposits of the Colorado group in the region from Monterrey west and beyond the Durango border, but with the exception already noted along the east limit of the cordillera, they are not known to have affected the country east of the Sierra Madre Oriental. The Fox Hills formation west of the front ranges of the latitude of Tampico, is largely composed of shales, sandstones, and even thin lenticular layers of chert conglomerate. Fox Hills sediments of the same nature extend northward into the Tula basin. Between the Tula basin and Saltillo the geology is almost unknown, but from Saltillo and Monterrey to the Rio Grande there is a great development with a maximum thickness of about 5,000 feet of terrigenous Fox Hills and Laramie. Since brackish-water fossils occur practically throughout this sequence there must have been great depression in the basin of deposition. Apparently the Fox Hills and Laramie sediments were derived from a recently uplifted land mass farther west. We have already mentioned that shore-line deposits appear in the basal Pierre 150 miles west-northwest of Panuco.

In the southern oil field, from 55 to 80 miles south-southeast of Panuco, there was probably great erosion between the Upper Cretaceous and later Eocene and Oligocene and it is noteworthy that the Washita is there the El Abra reef facies. All of the Colorado group, as well as later Cretaceous and the Lower Eocene, are missing from parts of the

south fields anticline. Since the remnants of later Cretaceous and overlaps of different stages of the older Eocene vary a great deal in amount in relatively near-by localities it is probable that there was folding along the south fields anticline in late Cretaceous or possibly very early Eocene, and that the fold in places remained above the surface of the early Tertiary sea as late as the younger Eocene. An alternative would be the local thrusting out of part of the section.

Definite evidence of marine Tertiary now existent west of the Sierra de Tamaulipas anticline is lacking. East and south of the Sierra de Tamaulipas there was extensive overlap, progressive westward, of the sediments of earlier Tertiary, but there is yet no definite evidence of angular unconformity between Cretaceous and earlier Tertiary. The region of higher structure of the Sierra de Tamaulipas anticline has no Tertiary sediments. Angular unconformity between Pierre Cretaceous and Midway Eocene is reported on the Rio Pesqueria by Cummins and Kennedy and on the next river south by Brantly and Powell.

The Chicontepec is a thick series of shales, sandstones, and chert gravels, the latter presumably derived from erosion of Cretaceous limestones, which crop out in a synclinal area between the eastern front ranges and the south fields anticline. The lower part of the Chicontepec may be late Cretaceous; the upper part appears to be early Eocene. The cross-bedding and coarseness of sediments of the Chicontepec suggest deltaic deposition in a sinking syncline, possibly contemporaneous with rising land areas in the eastern front ranges and south field anticline.

The lower and middle Eocene sediments of the Mexican part of the Rio Grande embayment are both thicker and more prevalently coarse than those of the same age in Texas. They were probably derived from the denudation of the Fox Hills and Laramie, which in turn most probably came from the west since in western Mexico there appears to have been folding, extensive intrusion, and metamorphism after Benton time, and great erosion during Fox Hills and Laramie. West-central Mexico and central Mexico are so largely covered with Tertiary volcanics that about all we definitely know of these provinces is that older Cretaceous strata were much folded and the regions subsequently greatly eroded before the outbreak of the volcanism.

The Sierra de Tamaulipas anticline was folded in the later epoch which formed the present eastern Mexican cordillera. It was during this time that the Tertiary beds east of the Sierra de Tamaulipas were tilted toward the Gulf of Mexico and the last folding of the south fields

occurred. The date of this great diastrophism is not established owing to the difficulty of accurately correlating tropical post-Eocene Tertiary beds. The folding is later than the age of the San Rafael deposits, which are commonly regarded as upper Oligocene or lower Miocene. A part of the marine Tertiary of the region, also tilted during the deformation, is regarded by some as younger than the typical San Rafael. After the deformation ceased the succeeding cycle of erosion was carried so near to completion that a peneplain was developed over the lowland plains. Thereupon, the peneplain was extensively covered with chert gravel largely cemented with calcium carbonate. These gravels extend from the Isthmus of Tehuantepec to Texas, where they are continuous with the Lafayette deposits. Not all of them are necessarily of the same age, however, as they may have gradually spread by being shifted from one site to another through a very considerable part of the later Tertiary. The mountain highlands are residual masses of rocks relatively more resistant to erosion and the writer has long sought, but never been able to detect, any erosion surfaces of pre-existing cycles in the highlands. The lowland plains were covered by rocks poorly resistant to denudational forces and are close to the Gulf, hence their peneplanation would be brought about fairly rapidly.

Since the deposition of the Lafayette gravels the plains area has been rejuvenated and a second and lower peneplain is now well on the way to completion. Regional uplift of the entire region appears to be the most adequate explanation of the rejuvenation. There is some probability, though not certainty, that the latest uplift was of the nature of a very broad and gentle tilting of the whole region toward the Gulf of Mexico. At least, the subsequent and latest erosion along the headwater and tributaries of the Rio Tamesi has excavated valleys miles in breadth and from 600 to 800 feet deep in territory formerly covered by a basaltic flow which overlies the Lafayette gravels.

OCCURRENCE AND ORIGIN OF OIL

The oil of the Panuco section varies in gravity from 12.5° to 12.9° Bé., contains from 3.5 to 5.7 per cent of sulphur, an average of 3.5 per cent (maximum 5 per cent) of gasoline, and has an asphalt base. Topila oil varies from 15° to 17.2° Bé. gravity. Ebano oil averages from 10.6° to 11.8° Bé. In the higher levels, particularly in the Mendez marl, a much lighter and better quality oil is encountered, but only in limited quantities and the supply is soon exhausted. For example, at Topila, oil with a gravity at least as high as 48.6° Bé. and with only a trace of

sulphur has been found. The lighter-gravity oils are prevalently of a light brown color and contain a relatively high percentage of volatile constituents. They are most probably filtered oils. The temperature of Panuco oil ranges from 90° to 120° F. The temperature ordinarily rises a few degrees upon the appearance of salt water.

One oil seepage occurred in the Panuco section proper and one small seepage in the Topila Estero at Topila. In the Ebano section are rather extensive seepages on faults and along the sides of basaltic intrusions. Several hundred seepages occur in the Tamesi valley north of the area of present production. These Tamesi valley seepages are in general very old. They began at least as early as the epoch of erosion which formed the broad valley during the post-Lafayette cycle. In the eastern part of the valley the epoch of valley erosion was followed by depression, forming an embayment of the Gulf which has not yet been filled to sea-level by alluviation. A large part of the Tamesi seepages are still active and a very large percentage of them have straight alignment along faults in the Pierre and Velasco which reach to the surface of the bedrock.

Oil has been found in wells from the top of the bedrock to 1,700 feet beneath the top of the Washita. Most of the production, however, has come from a zone about 500 feet thick situated 250 feet above and below the top of the Washita. Open fractures large enough to give profitable production are rare in the relatively non-competent Pierre and Velasco, being confined largely to the hard, brittle limestones. In the early days of the field profitable production was found as low as 800 feet beneath the top of the Washita. In a very few wells profitable production was procured underneath an upper horizon of salt water, but such cases are so rare as to suggest that the top water was present in local pockets or else that first an upper fractured zone full of water was found and lower down another and oil-bearing fractured zone occurred.

The drilling of a well absolutely barren of oil is very exceptional, yet the majority of wells drilled are not profitable producers. One-third of the total wells drilled before January 1, 1920, were commercially failures, while during the first quarter of 1926 fourteen-fifteenths of the total wells drilled were failures. Successful wells must be situated where fractures will be reached above the salt-water zone and this ordinarily is a difficult matter in regions where the situation of fractures has not been determined by previous drilling. In some places, the fractured zones seem to be scarcely wider than the average fault; in

others, there is a fractured zone of variable width in which production can be obtained. Wells placed within a very few feet of known faults have failed because no fractures were penetrated. As is ordinarily the case in faulting, displacements along faults do not run in absolutely straight lines and although most of the faults are nearly vertical very few are absolutely vertical. It is also impossible to foretell where they cease either horizontally or vertically and some parts of the faults have become imperviously sealed either by gouging or by deposition of mineral matter in them. Fairly extensive solution has occurred along faults, and in limestone has generally formed irregular and cavernous spaces. It is also possible in some places for the oil near the junction with the water to become so solidified by changing to heavy tar as to form an impervious medium, as in East Coast Well M-59 Laguna de la Milpa where oil of 11° Bé. gravity occurred surrounded by wells yielding oil of ordinary type. This well later yielded oil of the common gravity.

There are three definitely known source horizons of the oil. One is the thinly laminated bituminous strata interbedded with the limestones in the Benton, the second the bituminous shale referred to the Kiamitia, and the third and probably thickest the Kimmeridge Upper Jurassic. It is doubtful whether both the upper horizons are more than 75 feet in thickness. So far as has ever been determined there are no other source beds in the entire Cretaceous section. The Kimmeridge and Lower Portland in the cordilleran front ranges back of Ciudad Victoria are bituminous, but the deep test in Altamira on the north margin of the Tamesi valley proper found the Upper Jurassic to consist of cavernous and oölitic dolomite. The total thickness of the Upper Jurassic oil-bearing horizon in the Panuco field is not yet known. A fairly thick section of Lower Permian bituminous(?) shale is found in the mountains a short distance west of Ciudad Victoria, and it is possible other oil-bearing horizons of Paleozoic age may be found in the unexplored parts of the mountains between Ciudad Victoria and Linares, or in the front ranges south of the latitude of Tampico. Hence there are possibly pre-Jurassic oil-bearing strata underlying the Panuco field, and if so some of the Panuco oil may be derived from them, since it could probably migrate vertically along faults or the sides of igneous intrusions.

Both the Benton and Kiamitia(?) formations are still heavily saturated with bitumen although a large production of oil has been obtained. The unfractured Benton will not yield profitable production now and evidently did not so yield in the early life of the field. The Kiamitia(?) horizon did formerly yield profitable oil and gave a small

yield when last drilled, in September, 1924, but it is impossible to tell whether the oil may not have accumulated in fractures, the tops of which were sealed by the shale.

It is probable that the reason unfractured sections of the Benton will not yield profitable production is due to the very high percentage of volcanic ash which holds the oil by adsorption or other colloidal action. The heat radiating from the igneous intrusions may have distilled the oil from the Benton and Kiamitia(?) and the gas generated by the distillation and emanating from the magmas may have forced the oil into cavities. Oil so distilled would not be destroyed by the heat since it did not have free outlet to the surface and no oxidation could take place at the depth at which it was formed. The amount of oil so formed would be limited by the total volume of accessible spaces.

If such distillation of oil has occurred and if the only source beds of the oil are the Benton and Kiamitia(?), it would be desirable to know whether the igneous intrusions are mainly confined to the axial portion of the Sierra de Tamaulipas anticline. This we can not answer although extensive igneous intrusions reach the surface low on the eastern flanks of the anticline in the country between the Rio Soto la Marina and Rio Barbarena. If there has been upward migration of oil from the broad lower flanks of the anticline to the Panuco field the 2,600 barrels per acre average production of the field to date is not large, indeed it is ridiculously small. It seems reasonable to hold that such production could be derived from the Benton and Kiamitia(?) horizons of no more than the producing area. Unless there are very extensive fractures and spaces throughout the territory of the lower flanks, it is difficult to conceive how extensive lateral migration could have occurred. Computing the thickness of bituminous strata as 50 feet and the saturation as 10 per cent, only about one-fortieth of the total oil content has yet been produced, disregarding entirely any possible lateral migration from the flanks.

The discovery of bituminous Upper Jurassic at a depth not greater than 1,900 feet beneath the top of the Washita of the Panuco field has radically modified previous conceptions of the source of the oil and predictions of the future productive life of the field. The Kimmeridge shales and limestones are richer in bitumens than any other of the higher horizons and the oil in them is in a condition much more adaptable as a source of supply to the productive fractures. The Upper Jurassic is by far the greatest oil-bearing horizon which is known in the whole rock section exposed in the eastern cordillera. It is probably

within reasonable present drilling depth throughout the present developed field and it may well be possible to procure profitable production from this horizon after casing and cementing-off shallower-water zones in the overlying Cretaceous. There appears to be less reason than formerly for the somewhat prevalent view that oil production would not be obtained below the zone of first appearance of salt water, if, indeed, there was ever any adequate basis for such a view. It cannot be too strongly emphasized that underground conditions of both oil and salt water are very irregular in the Panuco field and it is altogether probable that zones of productive oil will be found within the Lower Cretaceous section overlain, underlain, and very probably surrounded by salt-water zones.

Traeger's view[1] that the main source beds of the Panuco oil are the Pierre and Velasco marls is probably incorrect. Neither of those formations shows any evidence of large content of bitumen either now or formerly. Those strata are, moreover, impervious to the passage of oil and water. The most that it appears possible to say for them is that they may have yielded some oil by distillation under conditions of igneous action and pressure prevalent in the field, as perhaps all marine sediments will do under like conditions, but the Upper Jurassic has certainly yet a very much greater content of available oil although subjected to greater heat and pressure than Traeger's supposed source beds.

Slightly more than half the total Panuco field production has come from the Panuco section proper. In the latter, nearly 7/10 total production is from the Tampuche syncline, nearly 3/10 from the Panuco anticline and 1/27 from the Halcon fault zone.

The Ingenio-Peralta greatly fractured section, with an area of about 40 acres, has produced 54,000,000 barrels, or 1,350,000 barrels per acre, enough oil to cover the 40 acres to a depth of more than 170 feet. The San Manuel fault along a distance of ¾ mile has produced nearly 42,000,000 barrels. Hence these two small areas have supplied nearly 2/5 the entire production of the Panuco section proper.

ORIGIN OF GAS

The composition of Panuco gas is 50 to 98 per cent carbon dioxide, with methane and possible other petroleum derivatives taking second place, the third constituent being hydrogen sulphide. There is also

[1]Earl A. Trager, "The Geological History of the Panuco River Valley and its Relation to the Origin and Accumulation of Oil in Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 1 (July, 1926).

probably a little sulphur dioxide. Some wells yield gases which will burn, but much—perhaps most—of the gas will not burn. The gas generally contains sufficient hydrogen sulphide to give its characteristic odor. The gas of some wells appears to be nearly pure carbon dioxide. Very few analyses of the gas have as yet been made.

The carbon dioxide is derived from two sources: (1) the metamorphic action of hot magmas intruding limestone (calcination) and eruptive after-effects have liberated vast quantities of it, and (2) a part has been derived by the dissolving action of the underground waters, already highly charged with the same gas from the first source, and therefore forming a solution which readily dissolves the limestone. The hydrogen sulphide appears to be either entirely of magmatic origin or derived from the reduction of sulphate in solution in the water, since practically all the pyrite and chalcopyrite found in drilling samples is entirely unaltered.

The hydrogen sulphide has evidently been the leading agent in the tarrifying of the oil, making it excessively heavy. The oxygen of the asphalt can be partially or entirely replaced by sulphur and the Panuco oil contains sulphur in the elementary condition up to the saturation point for that element at the prevailing temperatures.

ORIGIN OF WATER

The total salinity of the waters analyzed ranges from 2.8 to 7.2 per cent. It is apparent from this variation that the waters probably have different sources and that there is no mingling of the waters even in near-by fracture zones. The most concentrated water in the Ingenio lease comes from the shallowest horizon, but the well is in a greatly fractured zone and this water may really be coming from a deeper source than the other waters.

There is an alternative explanation. When pressure is decreased by the escape of gas, expansion lowers the temperature, especially of carbon dioxide, and ice forms around the head of the well even under a blazing tropic sun. Gas under low pressure will absorb more water than when under high pressure and it is possible that this absorption concentrates the percentage of mineral matter left in the water. If so, one would expect wells with larger volume of gas to have waters of higher salinity.

The high percentage of potassium is the most remarkable feature. There are at least three sources for the potassium: (1) from acidic holocrystalline rocks, (2) from potash-bearing dessication sediments asso-

TABLE IV

WATER ANALYSES FROM PANUCO AND TOPILA WELLS

A. Grams per Liter	1	2	3	4	5	6	7	8	9	10	11
Sodium	6.974	9.228	9.605	13.118	13.039	16.082	17.05	17.94	6.0445	12.224	.....
Potassium	1.6905	1.586	1.578	3.106	3.062	4.085	3.44	3.935	1.1455	9.283	.....
Ammonium	.0832	.0844	.0992	.1132	.1132	.1288	.....	.1216	.0328	.....	.....
Calcium	1.2395	.957	2.364	1.529	1.493	1.8	.74	3.179	.5785	1.024	.....
Magnesium	.8995	.750	1.172	1.286	1.299	1.587	.66	2.204	.3	.593	.....
Sulphate	.5485	.444	.437	.386	.403	.653	.37	.115	.1665	.396	.....
Chloride	16.912	18.370	22.952	28.496	28.352	35.174	29.80	43.418	11.156	27.269	.....
Bicarbonate	.2375	1.899	1.394	1.839	1.780	1.958	9.43	.771	1.854	2.756	.....
Hydrogen sulphate	.0442	.0362	.0306	.0644	.0524	.0498	.....	.0374	.0362	.....	.....
Silica	.095	.150	.160	.17	.13	.16	.....	.25	.045	.....	.....
Iron and alumina	.04	.09	.06	.06	.1	.1	.....	.05	.02	.....	.....
Total mineral content	28.7639	33.5946	39.8948	49.7676	49.8166	61.7776	61.49	72.021	21.379	53.545	.....
Potassium chloride	0.32%	0.30%	0.30%	0.59%	0.58%	0.78%	0.48%	0.75%	0.22%	1.37%	.....
B. Percentage Mineral Content											
Chloride	54.5412	52.2626	57.5407	.....	56.9025	56.938	48.5144	60.2859	52.1766	50.927	55.292
Sulphate	1.7689	1.2632	1.0955	.....	.8088	1.057	.6024	0.1597	.7764	0.739	7.692
Bicarbonate	0.7659	5.4026	3.4947	.....	3.5725	2.1583	15.352	1.0705	8.6712	5.147	0.207
Sodium	22.4911	26.2536	24.0797	.....	26.1552	26.0319	27.6574	24.9097	28.2678	22.829	30.593
Potassium	5.4518	4.5122	3.941	.....	6.1454	6.6123	5.6003	5.4637	5.3552	17.337	1.106
Calcium	3.9974	2.7227	5.9265	.....	2.9964	2.9136	1.2047	4.414	2.7033	1.902	1.197
Magnesium	2.9009	2.1337	2.9557	.....	2.607	2.5589	1.0748	3.0602	1.4031	1.107	3.725
Ammonium	0.2683	0.2401	0.2487	.....	.2272	.0466	.....	.1688	.1534	.....	.....

1. 416 Ingenio, from 125 feet below top of Washita. 2. 439 Ingenio, from 287 feet below top of Washita. 3. 432 Ingenio, from 332 feet from top of Washita. 4. 217 Halcon (A), from 65 feet below top of Washita. 5. 217 Halcon (B), from 65 feet below top of Washita. 6. 402 Ingenio, from Niobrara. 7. 411 Ingenio, from 180 feet(?) below top of Washita. 8. 509, Tamboyoche, Topila,[1] from 128 feet below top of Washita. 9. M-23, Potrero del Zacate, from 85 feet below top of Washita, diluted with pond water used in drilling. 10. Corona Pazzi 5, San Manuel, from depth of 1,806 feet. 11. Dittmar's average of 77 analyses of ocean water from many localities. *Challenger Rept., Physics and Chemistry*, Vol. 1 (1884), p. 203. Salinity 3.301 to 3.737 per cent.

Analyses 1 to 6 inclusive and 8 and 9 made by L. A. Penn, chemist, Pacific and Associated Oil Companies, San Francisco, California.

ciated with possible pre-Kimmeridge gypsum beds known in the cordillera or other saline residues of older date, and (3) from leaching of the acidic tuffs of the Upper Cretaceous.

Compared with sea water there has been addition of potassium, calcium, and bicarbonate radicals and subtraction of the sulphate and magnesium radicals. The addition of calcium and bicarbonate is common in waters in limestone. Waters associated with asphaltic oils are ordinarily poor in sulphate, which is taken out of solution, reduced, and added to the oil as sulphur. Moreover, the sulphates of these waters, by addition of organic matter, can be partly or entirely reduced to sulphides, and carbonic acid, acting upon the latter, may expel hydrogen sulphide and produce carbonates. Magnesium has probably been removed in the formation of dolomite, which is known only in a core sample 20 feet below the top of the Niobrara in Ita Mex Well 20, La Mula, Topila, but probably occurs more extensively.

The water migrates laterally only in the fracture zones; the strata between the fractures are impervious. Water, like the oil, does not occur at any definite stratigraphic horizon; hence it is simpler to class virtually all of it as bottom water. In a few wells, water has been cased off and oil obtained from a deeper level. Perhaps the reason this has been done but rarely is that it is the general custom to cease drilling whenever water is encountered, no effort being made to shut it out and drill deeper. The fact that either oil or water will be encountered if drilling is continued very likely indicates that fracturing is more plentiful in the lower levels of the limestone. Whether there are continuous oil or water horizons in the Lower Cretaceous or older rocks is something which has never been determined, no real effort to find out having ever been made.

The water from well 416 Ingenio has evidently been diluted by the addition of fresh water. It appears that there is a greater yield of oil and water for a period after the rainy season than during the rest of the year. All the water appears to be under sufficiently great artesian pressure to cause it to flow at the surface although the gas, which outlasts oil in profitable quantities, is an important agency in causing both oil and water to flow.

DRILLING AND PRODUCTION METHODS AND PROBLEMS

Panuco wells have been drilled with standard or rotary rigs or a combination of the two. Only a very few wells have been continuously cored through the Colorado group with the diamond drill.

The cheapest and most rapid method of drilling to the base of the Pierre is with the fishtail bit on either a rotary or a diamond rig. Since relatively little profitable production is derived from the Pierre and higher strata there is no great objection, from a production standpoint, to using the fishtail to the top of the Colorado group. Below the top of the Colorado group it is very poor policy to use the rotary although it is so used by some producers, a change being made to cone or roller rock bits at a depth a short distance above the top of the Niobrara. The use of the roller rock bit is most objectionable, since with it the formation is ground to flour and nothing definite concerning it can be determined. For the same reason the coarsest cutting cone bits should be used with rotary whenever possible. Standard tools are cheaper than rotary in the Colorado group and Washita and in these formations have the following advantages over rotary: (1) there is no column of fluid in the hole to inhibit or totally obscure oil or gas showings, (2) the standard tools have a tendency to shatter the rock beyond the walls of the hole and such shattering markedly increases chances of profitable production, and (3) the standard gives much better formation samples.

The main disadvantage of the standard tools is the seeping of small quantities of the heavy, thick, tarry oil into the hole, thus lowering the efficiency of the tools. If heavier tools were used this would not be such a serious disadvantage.

If the rotary is used for drilling below the top of the Niobrara, water as clear as possible should be used for fluid, except when it is necessary to seal off heavy gas which should be done by the use of barite or iron oxide. Should the bit penetrate a cavity yielding large production the oil will show its presence even when a heavy drilling mud is used. But lighter showings, many of which have proved to be profitable, may show very poorly if at all while drilling with the rotary and it is always advisable to bail the hole and test such showings when they appear. In most cases, also, it is probably very good practice to test by bailing whenever the drilling samples show oil-stained rock even if there is no oil showing in the circulating fluid.

Undoubtedly the cheapest method of drilling these fairly shallow wells is to use portable rotary to the top of the Niobrara and portable standard for the remainder, utilizing the pressure of the gas for power. Since Mexican operators are very conservative and have made little improvement in their methods, this and other desirable innovations have not yet been made.

It is the writer's conviction that the future of Panuco depends more upon a radical change in the present antiquated drilling methods than upon any other single factor. Since only about 1/40 of the conservatively estimated total oil content of the upper two and less important oil horizons of the field has yet been won, and 14/15 of the wells now being drilled are failures and certainly less than a half dozen of the operating companies have to date made a profit, it is quite apparent that there must be something fundamentally wrong with the methods now being used. The suggestion is advanced that continuous core drilling and the "shooting" of wells are worthy of a far more thorough test than they have ever had in this field.

Present methods of diamond drilling are not suitable for drilling wells for production in the Panuco field since the bore hole is of too small diameter. It is true that a bore hole 4 inches in diameter will deliver a sufficient quantity of oil, but in the limestone the larger the diameter of bore the greater the chance of finding fractures and the larger the amount of oil yielded by the fracture.

There is another fundamental reason for continuously coring the limestone with a large diameter hole. That reason is the very great desirability of "shooting" most of the wells. Cores afford precise information as to where both oil saturation and fracturing occur. They will show fracturing which may possibly be made to yield production in many localities where such fracturing will never be found by other methods of drilling. Such fractured or saturated zones can be "shot" with certainly a very good chance of procuring production. In perhaps the majority of wells it will be advisable to "shoot" the same interval several times, always using freshly-mixed nitroglycerine (this is difficult to do in Mexico), breaking down the wall with jack squib and thoroughly cleaning out after each shot, successively increasing the charge used and if necessary finishing with an extremely heavy shot.

There have been many wells drilled very near important fractures which have not yielded profitable production, but which, intelligently "shot," would almost certainly have produced. Relatively few wells have been shot in Panuco and those shot have not been markedly successful. As no one knows any definite horizon where production is to be expected, the operator is not on the watch for oil-saturated zones. Such zones at the best are not very definitely indicated by the rotary drill, although standard samples, if intelligently watched during the progress of drilling, present much better data. The only way by which the smaller fractures, which may indicate proximity to larger ones, can

be detected in either standard or rotary drilling is by the recognition of crystalline calcite that may line the walls. The calcite is largely ground to powder during rotary drilling and the evidence it affords is largely obscured or even destroyed. The cores which have already been taken show the presence of another class of smaller fractures which do not contain vein fillings. Such fractures will never be discovered when penetrated by either standard or rotary drill. It is really unaccountable how the prejudice against shooting has developed and persisted at Panuco, since shooting is well nigh universal in other limestone and hard consolidated rock fields.

Diamond core drilling and proper shooting will greatly increase chances of success under at least three general conditions prevalent in the Panuco field.

(1) A well situated close to a fracture, either known or reasonably predictable from structural data, should be "shot."

(2) There is possibility of fractures, of small amounts of vertical displacement, or joints which can not be predicted from structural evidence from the nearest wells, as the Panuco field is, in the main, by no means closely drilled. If fractures already drained of oil are sub-parallel and not connected one with the other through cross-fracturing, other oil-bearing fractures may exist in territory between those already developed and drained of oil.

(3) In some wells fractures have been penetrated by the drill only at relatively deep levels or, if at shallower depths, the shallower wells are spaced too far apart to have drained all the profitable oil from the higher parts of the fractures. In some places the actual strike of the fault has never been determined, because it is naturally better practice when it is ascertained that two wells are producing from the same fault to locate other wells along a straight line either connecting the wells already drilled or continuing their straight line direction. That the majority of fractures are not absolutely vertical is suspected because producing wells situated on straight lines derive production from different depths. This deduction is subject to the possibility that parts of the fracture are imperviously sealed by gouge or vein matter. The actual dip and direction of dip of a non-vertical fracture plane known from a single line of wells can not be determined from the available data. Under such conditions the drilling of shallower wells along the line already developed and "shooting" them will give increased chance of producing from the upper levels of the fractures. Core drilling will aid, of course, in giving evidence of proximity to fractures. A 7- to

8-inch diameter hole should be drilled for production by diamond drilling. This can be done by attaching ordinary rotary drill stem, preferably flush joint, to the present heavier diamond drilling machines by the use of a nipple placed beneath the floor of the rig or by constructing new types of diamond drills capable of handling larger diameter drill stem.

The fishtail bit can be used for drilling with the diamond machine until the top of the Niobrara is reached and the cost to that depth will be only slightly greater than with the rotary drilling machine. If the draw works of the diamond drilling machine are further improved so they will operate as rapidly as those of the rotary there should be no difference in cost. Below the top of the Niobrara an average rate of 40 feet per 24 hours can be maintained with the diamond drill in the comparatively shallow Panuco area. This will be cheaper than standard drilling but will cost about twice as much as rotary drilling. The hard cherty limestone encountered below the top of the Washita should be drilled more cheaply by diamond than by either rotary or standard.

The usual practice is to cement 8-inch casing near the top of the Niobrara and to proceed with open hole beneath. Few producing wells are tubed although when many large producers are brought in with the rotary the drill stem is left in the hole and this partially inhibits the escape of gas. Nearly all wells are partially choked in while producing and the flow opening is made gradually smaller as the oil shows emulsion and salt water. The choker is used not so much to inhibit escape of gas as it is to prevent premature drawing of emulsion and salt water into the well, since very few wells ever cease flowing. Generally the pressure increases when a large quantity of salt water makes its appearance, mainly because the resistance to flow (viscosity) of water is much less than that of the oil and the temperature generally rises upon appearance of water. The usual practice of making a well flow its own oil to a distant pipe line or pumping station is probably detrimental to the life of the well because variations in temperature induce oscillations in pressure generating agitation which tends prematurely to draw-in salt water or emulsion.

There has been to date very little utilization of the pressure of the plentiful supply of gas in drilling, pumping, and other power purposes. If the gas is separated from the oil and then used for pumping it from the well, the rate of yield can be safely increased and the flowing pressure of wells kept more uniform. There is evidently enough gas still in the

field for nearly all drilling, transportation, and power purposes, although some oil must be burned in heating that passing through pipe lines.

It may be thought that these criticisms are unduly unfavorable to the average producer, yet it is a fact that oil has been continuously produced in Mexico during a period of fifteen years under conditions far more difficult than in any other country and those familiar with the situation know this has been no mean achievement.

CONCLUSION

Geology would not hold its own among the sciences if it did not make progress. Oil, like gold, is widely distributed in the rocks and both have what may be termed the more normal modes of occurrence and in addition several sporadic modes of occurrence. The latter are apt to be more instructive than the former. Panuco, with its extraordinary conditions, teaches some valuable lessons.

Active seepages of oil are known, both in highly deformed rocks and those subjected to considerable contact metamorphism, in the Mexican states of Durango, Coahuila, and Tamaulipas; and rocks of the Mexican West Coast states which have suffered both dynamic and contact metamorphism exhibit oil concentration and seepages. These occurrences cast grave doubt upon the validity of the carbon-ratio hypothesis. Metamorphism produced through folding and igneous intrusion may under some conditions change the original nature of the oil in a manner somewhat analogous to the change from lignite or bituminous coal to anthracite or graphite under similar conditions, but unless sufficient oxygen is present to bring about actual combustion of the oil, or there is free outlet for its escape, it will not be destroyed. The writer has found vesicles in basalt filled with oil in the state of Santa Catharina, south Brazil. The basalt is there absolutely fresh and solid without even the slightest cracks connecting the vesicles with the outside. Hence it is probable that the oil was present in the molten magma and was not destroyed by igneous processes. There are said to be similar occurrences in the southern field of the Tampico area. Vesicles in basaltic silts at Panuco are filled with oil. Another fundamental consideration not taken into account by the carbon-ratio hypothesis is increase in metamorphism induced by the greater pressure at greater depths. Also in places where a large thickness of rocks has been removed since the time of oil formation and accumulation, the pressure is now considerably less.

Panuco furnishes information along another line. Wherever a dense limestone may be oil-bearing, whether in Mexico, the Trenton field

of Ohio-Indiana, the "Mississippian lime" and older formations of the Mid-Continent, the Pennsylvanian and Permian limestones of the southwestern United States, or in Persia, or Egypt, or anywhere else, anticlinal structure is not absolutely essential for concentration of oil in profitable quantities. All such limestones have fractures or more or less irregular open spaces of other modes of origin. If oil source rocks occur either above or below such limestone, regardless of the attitude of the strata, oil is likely to be concentrated in any cavities or crevices which exist in the limestone and which have more or less free communication with the source rock.

DISCUSSION

DISCOVERER OF GORHAM OIL DISTRICT, KANSAS

Because of certain incorrect statements recently appearing in the press on the history and development in the new Gorham oil district in Kansas, I should like to review the circumstances which led up to the discovery of the Gorham structure and the drilling of the first well on it by the Producers and Refiners Corporation.

Following the completion of the Oswald No. 1, the discovery well, in the Russell field, I did considerable detail mapping in Russell County in December, 1923, which led to the discovery and drilling of two small structures southeast of the discovery well in Russell. Mr. J. S. Irwin, then a member of the geological department of the Producers and Refiners, was assigned the examination of an area several miles south of Gorham, soon after January 1, 1924. In following the Post Rock horizon northward, he discovered the south slope of the Gorham structure and called attention to his find. Together we made another examination of this feature, after which he was assigned the problem of mapping the Gorham area in detail. It was the results of Irwin's detail work at that time, in January and February, 1924, which led to recommendations to lease the Gorham area and drill a test well, which was done by the company without further delay. The statement, therefore, that I originally worked the Gorham area for the Producers and Refiners Corporation is incorrect, and I desire to have the truth known and to give full credit to Mr. Irwin for the discovery of this promising area.[1]

F. F. HINTZE

DENVER, COLORADO
February, 1928

[1]EDITOR'S NOTE.—Mr. Hintze was in charge of the geological department of the Producers and Refiners Corporation at the time of this discovery.

REVIEWS AND NEW PUBLICATIONS

The Geology of Venezuela and Trinidad. By RALPH ALEXANDER LIDDLE, J. P. MacGowan, Fort Worth, Texas, 1927. 552 pp., 169 half-tones and 24 sections and maps. Price, $7.50.

This book is the first comprehensive publication on the geology and stratigraphy of Venezuela. It is by far the most important contribution to Venezuelan geology that has been published to date. The text is remarkably free from inconsistencies in spelling in view of the great number of foreign words, fossil names, and the technical nature of the subject in general.

The discussion of the general physiography of Venezuela and Trinidad is considerable in amount and gives a fairly complete background for the discussion of stratigraphy which follows. The systematic manner in which rocks of contemporaneous age, though occurring in various parts of the country, are described, enables the reader to grasp the information readily. This manner of presentation necessitates a considerable amount of repetition, but this, to one not intimately acquainted with the country, is in many respects desirable.

Few subdivisions of pre-Paleozoic rocks have been made, but undoubtedly in time enough evidence will be collected to warrant designation of formations. The local occurrence of Devonian, and probably Silurian, indicates what may be expected when the entire country has been examined as carefully as particular areas.

Liddle has had first-hand information on the eastern, the western, and southern districts of Venezuela, and has done a great amount of detail work in these districts. He also has a good reconnaissance knowledge of the intermediate area.

The book is primarily a study of the stratigraphy and distribution of the Cretaceous and Tertiary sediments carefully correlated with the major tectonic features and the probable location and duration of the various old land masses. His recognition and discussion of the igneous and metamorphic occurrences of Paleozoic and pre-Paleozoic rocks are of particular value to the commercial geologist, who is not justified in spending much time in the study of these formations.

The discussion of the Cretaceous, Eocene, and lower Oligocene horizons and their different phases is clear-cut and accurate. The reviewers believe that Liddle has done an especially valuable piece of work in the presentation of these in such a logical and precise manner.

In that part of the book which relates to the areal geology and the age determination of the stratigraphic equivalents of the upper Oligocene and the lower Miocene of the west-central Falcon area, the reviewers find it impossible to agree with Liddle in many respects.

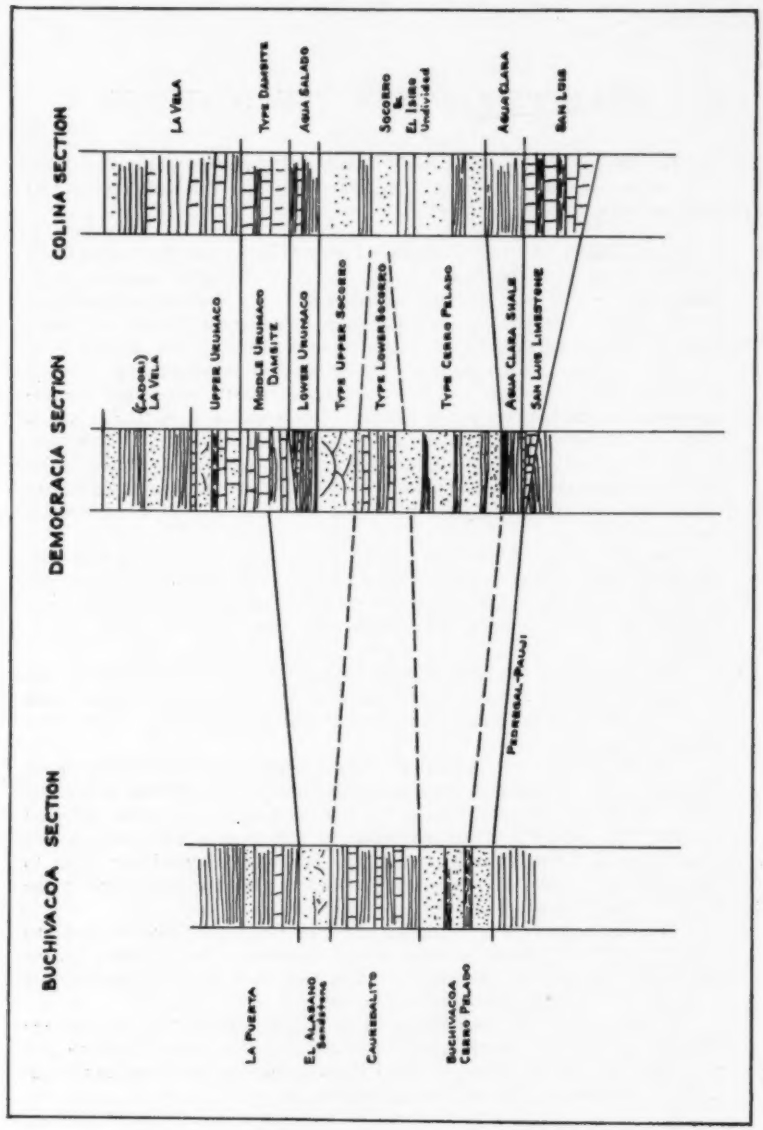

FIG. 1. Geological cross-sections in Venezuela.

In order to clarify the issue it seems best to set forth here a type section (Fig. 1), in a comparatively simple structural area, upon which both Liddle and the reviewers agree, and to that type section relate the various questionable points of correlation. Probably the most desirable area for this type section is the district of Democratia, state of Falcon. In this particular area there are four type localities which have been recognized by several geologists since the first work by Arnold from 1912 to 1916. In addition there are two localities which are without doubt exact equivalents of the type localities chosen by Liddle. Liddle has agreed that the formations at these localities are the same formations as those described by him.

The section is as follows:

Pedregal shale. (Pauji).—Lower Oligocene on the basis of a considerable foraminiferal fauna. Type locality, Pedregal Valley near the town of Pedregal. Thickness 2,000 to 2,500 feet of massive calcareous, black to blue-black shale with a splintery fracture. This shale carries some thin lenticular blue and blue-black limestones. Calcite stringers and gypsum hillocks are characteristic.

San Luis limestone.—Middle Oligocene on the basis of the foraminiferal fauna. Type locality, the town of San Luis, continuing along the San Luis uplift to the vicinity of Agua Clara. Thickness variable. This series consists of lenticular massive blue to blue-black limestones weathering white especially near the top. Members range from a few inches to 200 feet in thickness, and are separated by inconspicuous shales, generally thin.

This formation lies conformably above the Pedregal shale and unconformably below the Agua Clara shale and is separated from the latter by a rather coarse basal sandstone a few feet in thickness.

Agua Clara shale.—Upper Oligocene from stratigraphic position and some paleontological evidence. Type locality, town of Agua Clara. Thickness 1,600 feet. This formation is dominantly shale, purplish, light blue and reddish in color. It is not so hard or calcareous as the shales of the underlying San Luis and Pedregal. Below, it lies unconformably over the San Luis. Above, it is, so far as known, conformable with the overlying Cerro Pelado formation, the contact between the two being more or less arbitrary.

Cerro Pelado formation.—Oligocene-Miocene transition or basal Miocene. Type locality, Cerro Pelado, a peak in the Cerro Pelado range west of the town of Agua Clara. The entire series consists of near-shore, shallow-water, and some continental deposits. Prominent sandstones, sandy shale, and some pure shales make up the series. The colors range through white, yellow, gray, brown, and red. Typical fresh exposures have a greenish tint. Near the base of the series are several beds of coal and lignites (See Plate XLVI, Fig. 2, labeled Socorro series. This is about 750 feet above the base of the Cerro Pelado formation). Conformable with Agua Clara shales below. Above, the contact is rather difficult to determine away from the type locality. At the type locality a local unconformity is taken as the upper limit.[1]

Socorro series.—Lower Miocene on the basis of ample fossil evidence. Type locality at Socorro, from the first sandstone bluffs south of Urumaco to

[1]Liddle has included a great deal of the Cerro Pelado in his Socorro series. The dividing line as originally described by the senior reviewer in company reports is more than 1,000 feet higher in the section.

the sandstone at San Raphael. Thickness 3,000 feet. This formation may be divided into two units, the lower consisting of sands, shales, marls and limestone with considerable gypsum. Sands are somewhat concretionary, white, yellow, or brown, weathering to light brown. The shales are generally blue, but in places red. The gypsiferous marls are fossiliferous. The upper part of the Socorro consists of 700 to 1,000 feet of non-marine sandstones, peat, and paper shales. There are no limes, marls, or other fossiliferous horizons. Sandstones are cross-bedded and give every appearance of continental origin. Below, the Socorro series lies locally unconformably on the Cerro Pelado. Above the Socorro series and below the lower Urumaco member of the Damsite limestone there is a very slight angular unconformity with fragments of the Socorro series in the basal member of the Urumaco.

Damsite limestone.—It has been found advisable in the Democracia area to divide the Damsite limestone into three members, lower, middle, and upper Urumaco. The age of the formation here exposed is without doubt middle and upper Miocene.

The lower Urumaco beds outcropping directly south of Urumaco have a thickness of 1,400 feet. They consist of dark blue shale, a little sandstone, and several thin, hard limes. It is near the base of this formation that the Richmond-Sun well obtained production.

The middle Urumaco beds outcrop from the town of Urumaco for a distance of about 1½ kilometers northward and have a thickness of 1,800 feet. They consist largely of shale and sandy lime, shales predominantly blue and limestones ordinarily yellow or brown. This formation may be correlated definitely with the type locality of the Damsite limestone and is the exact equivalent of the beds outcropping at the dam at Cuajarao, Arnold's type locality. The upper Urumaco beds consist of about 2,000 feet of coarse sands, lenticular and unevenly deposited, marls, shales, and some peaty coals outcropping north of the middle Urumaco beds. They are in evidence surrounding the locality of the Richmond-Sun well north of Urumaco. The lower part of these beds is of continental origin overlying the marine members of the middle Urumaco. They are Miocene in age but somewhat younger than Gatun; probably upper Miocene. The lower Urumaco lies unconformably above the upper Socorro series. The upper Urumaco is separated from the middle Urumaco, or typical Damsite, by non-marine sandstones and coals. So far as known the La Vela series, locally known as Cadori beds, overlie the upper Urumaco series conformably.

Considering this column as a whole, it may be noted that the Pedregal shales represent a rather long time period as may be inferred from the type and thickness of deposited sediments. The massive overlying San Luis limestone also represents a considerable time interval. The Agua Clara shales represent a somewhat shorter period.

The Cerro Pelado formation, on the other hand, shows evidence of nearshore, shallow-water deposition, and probably represents a comparatively short period of deposition. The lower Socorro series above represents slightly slower deposition, inferred from the presence of several limestone beds. The continental and shore deposits of the upper Socorro series represent another period of speedy erosion which probably did not last for any great length

of time. Above the Socorro series the Damsite limestone group represents a long time interval when the plentiful limestones and shales of that formation were deposited. Taking this into consideration, it seems apparent that the Agua Clara shales and the lower Socorro series, though separated by a considerable thickness of sandstone, are closely related in time; consequently, paleontological evidence correlating outside beds either with Agua Clara or with Socorro may prove dangerous unless detailed structural studies are carried on and the paleontological correlations are checked carefully against lithological and structural data.

The foregoing type section indicates that Liddle and the reviewers are agreed upon type San Luis, type Agua Clara, type Cerro Palado, and type Socorro with some modification and are totally in accord in regard to Damsite lime.

In order further to clarify the issue the reviewers propose to describe for the purpose of this discussion the application of these names to the formation in the Rio Cauredalito which Liddle describes beginning at the last paragraph, page 263, and continuing on page 264. Here under the name San Luis limestone and Agua Clara shale, Liddle describes a formation which was designated as Cauredalito lime in private reports as early as 1923. Liddle makes an arbitrary division of this formation at a 25-foot limestone bed which is known locally as the key lime. Such an arbitrary division, in this locality at least, is apparently not justified. The reviewers are in accord with Liddle's correlation of the Quiros beds, with the El Mene beds, with the Hombre Pintado oil-bearing horizons, the La Planchada, and at least part of the Cauredalito lime; they do not agree, however, that this formation is the equivalent of the Agua Clara shale. Nor do they agree that the Agua Clara shale is the equivalent of the Agua Salada clays still farther east. The fauna of the Agua Clara formation at this type locality is largely a micro-fauna presenting many specimens but very few species of *Foraminifera*. This fauna suggests an upper Oligocene horizon. It contains practically none of the larger fossils so common in the beds at the localities previously mentioned. On page 269 of his book Mr. Liddle publishes a faunal list from Quiros. Of this list of thirteen specific identifications, nine are typical Miocene forms. The other four have a much greater range than Miocene both above and below. Of these nine Miocene forms two are restricted to the Socorro series at the type locality of the Socorro series. The other seven range upward into the Damsite. Referring to Hodson's publication on the Turritellas of Falcon,[1] he shows two additional Turritellas from Quiros not given in Liddle's list which in Democracia are restricted to the Socorro series. The paleontological evidence throughout Liddle's book indicates that the Quiros, El Mene, Hombre Pintado, and at least part of the Cauredalito lime are more closely related to the lower Socorro series than to the Agua Clara formation. From a lithologic comparison it seems probable that these beds are the equivalent of the Socorro rather than of the Agua Clara. The stratigraphic sequence in the Buchivacoa area, compared with the stratigraphic sequence in the Democracia area, seems to indicate that a more logical correlation would be that of the Socorro with a part of the Cauredalito and Quiros. Underlying the Cauredalito lime at the

[1] *Bull. of American Paleontology*, Vol. XI, No. 45 (1926), Ithaca, N. Y.

type locality are the Buchivacoa Cerro Pelado beds. (Formation names used in private reports as early as 1923.) Below these massive sandstones, which are similar to type Cerro Pelado in general aspect, lie black shales which are continuous with the Pedregal shales in the Pedregal Valley. Acceptance of Liddle's correlation will necessitate the placing of a considerable unconformity between the Pedregal shales and the Agua Clara-San Luis Group and the deposition during that interval of 2,500 feet of sandstones at a horizon where no similar sandstone formations are found in the whole state. As regards structural relations between the two areas, the Buchivacoa Cerro Pelado may be traced eastward to the vicinity of type Cerro Pelado. Between the recognizable Buchivacoa Cerro Pelado and type Cerro Pelado there is a narrow interval of faulted and folded sediments. However, it does not seem to the reviewers that there is sufficient disturbance in this area to bring into juxtaposition sediments which are normally 6,000 feet apart as they must be if Liddle's correlation is correct, and in addition completely eliminate the lower formation (Buchivacoa Cerro Pelado) east of such a fault and the upper formation (type Cerro Pelado) west of the fault. Such a postulated fault would also bring into juxtaposition in the Pedregal Valley on the south two black shales of identical lithologic characters, one of which lies below Buchivacoa Cerro Pelado and the other below type Cerro Pelado.

In the previous discussion of the time interval required for the deposition of Cerro Pelado sediments the reviewers brought out the fact that Socorro time and Agua Clara time are closely related. Lithologic, stratigraphic, and structural evidence can be satisfied only if Buchivacoa Cerro Pelado which lies below Cauredalito is found to be equivalent to some part of the type Cerro Pelado, and Cauredalito to be the equivalent of some slightly higher part of the Cerro Pelado or possibly lower Socorro series. The formations above the Cauredalito lime, higher than La Puerta, may be safely correlated with the uppermost part of the Damsite limestone. The intermediate portion between the Cauredalito and the La Puerta formation, commonly called the El Alasano sandstones, must be the equivalent of some part of the Democracia section between the lower Socorro series and the typical Damsite fauna of the middle Urumaco. There is a possibility, although not required by this correlation, that the El Alasano formation may be more or less local and be represented by the unconformity between the upper Socorro series and the lower Urumaco series.

Liddle in his book makes the Agua Clara shale the equivalent of the central portion of the Mesa Saladillo beds outcropping to the south of Coro. These beds have been detailed and traced eastward from this vicinity into the typical Agua Salada clays at Anton Coro. At Mesa Saladillo these beds have largely lost their lithologic character, the upper part having graded into the lower part of the Damsite and the lower part having graded into the upper part of the El Isiro coal series, the equivalent of the Cerro Pelado-Socorro. They are, then, younger than the Cerro Pelado, which in turn lies above the Agua Clara shales. From this it is sufficiently evident that the Agua Salada clays must, in the reviewers' type section, be the equivalent of the lower Urumaco limestones and shales or of some part of the Socorro series and certainly cannot be correlated with the Agua Clara shale. They can, however,

be correlated, without any serious difficulty, with the Cauredalito, Quiros, and other formations to the westward. This difference brings the reviewers' correlation in all important parts in accord with the correlation of Liddle with the sole exception that not all of these beds which are correlated are the equivalent of the Agua Clara shale. Therefore, in the reviewers' opinion, wherever the term Agua Clara shale is mentioned in Liddle's book, except where referring to the type locality at Agua Clara, it should be considered as referring to that part of the section which lies between the Cerro Pelado formation and the lower Damsite. This question of correlation is of the utmost importance from the point of view of petroleum production throughout the state of Falcon, inasmuch as through the district of Buchivacoa all of the important oil seeps are associated with this group of beds. In addition, in the Lake Maracaibo basin it is supposed that practically all present production is coming from this horizon in the producing fields. Furthermore, in the eastern part of the state of Falcon, Agua Salada clays are petroliferous throughout their section and in a wide areal extent. There is no known production in this area, accepting Liddle's correlation, from horizons above, with the exception of the Richmond-Sun well north of Urumaco. If the correlation may be accepted as outlined in this review, the Richmond-Sun well will be found to produce from the same horizons as those which are so universally petroliferous both on the east and on the west or from horizons only very slightly higher. It may be stated that at the time Liddle's correlation was first promulgated by other geologists working in that area, it was forecast by them that no production would be found east of the river Rio Borojo, due to the great depth at which the Agua Clara sediments would be found. The completion of the Richmond-Sun well has conclusively proved these forecasts to be slightly in error, either due to erroneous correlation or the presence of a 6,000-foot unconformity at the Urumaco well, for which there is as yet no evidence. Also production has been obtained in eastern Falcon, probably from the Curamichate sands which correlate with the upper part of the Cerro Pelado or possibly lower Socorro.

In conclusion, the reviewers wish to state that, with the exception of the Agua Clara correlation, the book as a whole is a very complete, comprehensive, and satisfactory presentation of the geology of Venezuela. It should certainly be in the hands of every geologist interested in Venezuela.

S. H. WILLISTON
C. R. NICHOLS

DALLAS, TEXAS
February, 1928

Die Verwässerung von Erdölfeldern, ihre Ursachen und Bekämpfung (*The Flooding of Oil Fields, its Causes and Control*). By WALTER KAUENHOWEN. Julius Springer, Berlin, 1928. 80 pp. and 54 figs. Price, 7.50 M.

The purpose of this small book is to summarize for the German-speaking petroleum technologist the problem of the flooding of oil pools, with a discussion of the causes of the invasion of oil sands by water and of the methods of controlling flooding that has already taken place and of preventing future flooding. The main topics of the book are: (1) flooding and its disadvantages; (2) examples of the flooding of oil fields, Hanover, Tustanowice, Mexico,

United States; (3) the water relations in oil fields, origin and division of waters in oil fields, determination of water horizons, application of dye stuffs to the movement of water, chemical composition of saline oil-field waters; (4) the causes of the invasion of oil fields by water, nine causes discussed; (5) the methods of water shut-off with minor discussion of plugging old wells and the use of back pressure and the legal regulations for the prevention of flooding; (6) an appendix giving a digest of the Polish, Roumanian, Prussian, Argentinian, and Californian regulations regarding water shut-off.

As most of the information of this book is already in English, the book will not appeal to the American petroleum technologist, but it gives an interesting and valuable digest of the American literature on the subject with the addition of considerable material from experience in Galicia and elsewhere. It should be an important contribution to the German literature of petroleum technology.

DONALD C. BARTON

HOUSTON, TEXAS
February, 1928

Surface History of the Earth. By JOHN JOLY. Oxford University Press, American Branch, 35 W. 32nd St., New York, 1925. 192 pp., 13 plates, 11 figures. Price, $3.00. Postage, $0.17.

This book is a very interesting development of the theory of isostasy. Joly does not agree with the Pratt conception of isostasy but combines the ideas of Wegener and Airy. He considers that the continents are made up of lighter rocks which float upon a basaltic substratum. This basaltic substratum is considered to form the floor of the ocean basins.

The world-wide occurrence of large flows of basalt is noted. The Deccan traps of India, the Columbia River lavas, the Siberian traps, the Palisade basalts, and the large flows of Australia and Patagonia are examples. These rocks are very similar in composition, and resemble very closely the samples of basalt which are reported from the floor of the ocean and from volcanic islands in the ocean. Joly argues that the constancy of composition, the world-wide distribution and the persistence through geologic time of these rocks is evidence of a common reservoir. Daly considered basalts to be the primary magma injected along abyssal fissures. Joly considers this good evidence of a basaltic substratum with probably a heavier stratum below and probably much iron and nickel in the interior of the earth.

The continents are considered to float upon the basaltic substratum, displacing their own mass of basalt. The average density of continental rocks is 2.67 and that of basalt is 3.0. The average emergence of the continental areas is given as 3.22 kilometers; therefore it is necessary to have 26.05 kilometers of continental rocks submerged in the basalt to float the continents. This gives an average thickness of 30 kilometers for the continental crust. Several authors are quoted who have studied seismic waves and estimate the thickness of the crust as 30 to 35 kilometers. The velocity of seismic waves is said to be greater under the oceans, indicating a denser material. Wegener considers that the distribution of terrestrial magnetism indicates that the rocks of the ocean floor are more magnetic than the continental rocks; therefore that they are basaltic.

Joly states that all rocks of the earth's surface are radioactive. Acid rocks are the richest in radium and thorium. The radioactive minerals in 1 gram of granite generate 30×10^{-14} calories per second. Joly estimates the amount of heat generated in a column of granite rocks 31 kilometers deep and finds it to agree very closely with the amount of heat escaping from the surface of the earth. He concludes that the heat generating in the substratum must be accumulating, both under the land and under the sea, since the sea water will cool the upper part of the suboceanic crust and prevent the escape of heat. Experiments are cited which indicate that the rate of radioactivity is unaffected by heat or pressure. The temperature at the base of the crust is estimated by Joly to be about 1,150° C., which is the temperature of recently solidified basalt. Liquid basalt solidifies at 1,050° C. and solid basalt liquifies at 1,150° C. Joly estimates that, in approximately 33,000,000 years, radioactivity would generate sufficient heat in the basaltic substratum to cause it to liquify.

The volume of liquid basalt is about 12 per cent greater than that of solid basalt. The continents would therefore displace a greater volume of basalt and would settle deeper into the basaltic substratum. This would bring the continents lower with respect to the ocean basins and the seas would transgress the land. The greater volume of the basaltic substratum would slightly increase the volume of the earth. This would cause tensional stresses in the crust, resulting in rifting and basaltic flows, both on the continents and under the oceans. Tidal forces would cause the continents to shift westward, thus allowing the substratum to be cooled by the oceans. Joly believes that if this shifting did not take place, superheating beneath the continents would cause catastrophic igneous effects which might destroy all life.

The cooling of the substratum would cause emergence of the continents and shrinkage of the earth. The decrease in circumference would cause the sea floor to thrust against the continents, crushing the coasts inward and forming raised borderlands. The thrusts from the sea would thicken the crust as well as uplift it, thus forcing some of the crustal material downward. The American mountains trend north and south, relieving east and west stresses. The Eurasian mountains trend east and west, relieving stresses from the south and southeast. Jeffreys estimates the reduction in surface area of the earth due to orogeny as 1,872,000 square kilometers. Volcanoes are near the sea as thrusts from the sea floors cause them.

Erosion sets in, tearing down the mountains, furnishing material for deposition in geosynclines which will be in turn uplifted.

In this manner Joly traces the cycles of earth history. He notes six great revolutions or periods of mountain-building. The Algoman following the Sudbury deposition, the Grand Canyon or Killarney closing the pre-Cambrian, the Caledonian in Silurian time, which was more accentuated in Europe, the Appalachian closing the Paleozoic, the Laramide closing the Mesozoic, and the Cascadian closing the Tertiary. Joly says that the crust at present is as reposeful as it ever will be, but that there are now slow crustal movements reminiscent of the past or prophetic of the future.

The beginning of the earth is of course unknown. The age of the earth, as estimated by the rate of sedimentation and the amount of sediment depos-

ited, is 100 million years. The amount of sodium in the ocean divided by the amount brought in annually by rivers gives 175 million years as the probable age of the earth. The rate of decomposition of uranium favors an age somewhat over 100 million years while that of thorium suggests an age of about 500 million years. Joly estimates the length of a heat cycle as 40 to 60 million years. Since at least 5 cycles are indicated by geological history, he estimates the age of the earth to be 200 to 300 million years.

Joly suggests that the decline of radioactivity will eventually end the periodic uplifts, that the continents will sink into the oceans and life will cease.

Joly's book and *Isostasy* by Bowie form a very interesting contrast. They found their ideas on the same geodetic data but differ radically thereafter. They differ in their conceptions of isostasy itself, in their ideas of the thickness of the crust and in their theories of the relation of isostasy to earth movements. Joly endeavors to use all available geological data and to work out a system which harmonizes with all of the known facts of geology.

Probably many geologists will discount the importance of radioactivity and many will find it impossible to accept Joly's conception of a liquid substratum. But whether or not one agrees with Joly, his book contains a great deal of valuable information and is well worth reading.

LYNDON L. FOLEY

TULSA, OKLAHOMA
February 15, 1928

The Genesis of Petroleum. By PERCY E. SPIELMANN. Ernest Benn Ltd., London, 1923. 72 pp.

This book reviews the development of the theories of the origin of petroleum. The author has given special attention to the period 1912-22. Many of the present day theories are much older than is realized by most geologists. Agricola, in 1544, sought to correlate oil, bitumen, and coal. Haquet, in 1794, concluded that the Galician oils originated in the decomposition of sea animals. Henkel, in 1725, considered plant and animal remains to be the source of oil.

In 1804 Humboldt suggested that petroleum was "the product of distillation at an immense depth and that it takes place in the primeval rocks where the force of all volcanic action resides." Many chemists have supported the inorganic theories of the origin of petroleum. Among these are the carbide theory, which is based on the action of water on metallic carbides, and the volcanic theory, which is based on the presence of hydrocarbons in volcanic gases. In 1921 Hixon maintained that petroleum must be inorganic because it is utterly unlike organic oils.

The organic theories include distillation of organic matter within the earth by means of heat, theories of origin from vegetable matter and theories of origin from micro-organisms and animal remains. The chemistry of oils and its significance is discussed. Many laboratory experiments bearing on the chemistry and origin of oils are described. The author also discusses bacterial action.

The author concludes that the evidence is overwhelmingly in favor of the organic origin. The tendency appears to be to consider each problem separately as to animal or vegetable origin rather than to assert a common source.

It is concluded that the amount of organic material which has been buried has been ample to account for all of the petroleum. Aerobic bacteria are considered to be an important factor in beginning the decomposition of organic matter accumulating in brackish seas or lagoons. The migration of oil is supposed to change the oil chemically and physically by filtration through finely divided inert mineral matter. The composition of the oil in any particular locality will be the result of (1) the nature of the parent substance, (2) dynamo-chemical alteration due to earth movements, (3) nature and degree of modification during migration, and (4) geological age of production.

LYNDON L. FOLEY

TULSA, OKLAHOMA
February 20, 1928

Geology and Natural Resources of Colorado. By RUSSELL D. GEORGE. Volume 1 of the University of Colorado Semi-Centennial Series. The University of Colorado, Boulder, Colorado, 1927. xv + 228 pp. Price, $2.00.

As a part of the celebration of the semi-centennial of the University of Colorado in November, 1927, the Board of Regents authorized the publication of a series of five volumes, scientific, historical, and philosophical, designed to be of interest primarily to citizens of the state. It was very logical that one of these volumes should deal with geology and natural resources. The chapters on general geology occupy 85 pages and the remainder of the book is devoted to natural resources, ranging from metalliferous deposits to climate and scenery. An enormous and heterogenous mass of information is crowded into small compass. The general treatment fails to appeal to the reviewer as it is too technical for the layman and not sufficiently detailed for the technical reader.

Professor George believes that conditions in Colorado justify the belief that the state has vast undiscovered mineral wealth and that there is before her a long period of mining activity. The resources of the prospector have been exhausted and it is now a long time since he has presented the state with a major discovery of any kind of ore. Seventy-five per cent of the area in the zone favorable for ore deposition, however, cannot be worked by ordinary prospecting methods and the great promise of the future lies in prospecting by geophysical methods.

The area of commercial oil shales in Colorado is more than 2,000 square miles and this gives promise of being the state's greatest mineral resource.

E. RUSSELL LLOYD

DENVER, COLORADO
February, 1928

RECENT PUBLICATIONS

CALIFORNIA

"Oil and Gas Exploration in Southwestern Humboldt County, California." *U. S. Geological Survey Press Notice 21,122*, March 5, 1928. 9 pp., map and cross-sections. Free.

GENERAL

"The Eötvös Torsion-Balance Method of Mapping Geologic Structure," by Donald C. Barton. *Technical Publication No. 50, Amer. Inst. Min. and Met. Engineers*, 29 West 39th Street, New York City, 1928. 51 pp., 13 figs.

Allgemeine Petrographie der "Ölschiefer" und ihrer Verwandten mit Ausblicken auf die Erdölentstehung (*Petrography of Oil Shales with Reference to Origin of Petroleum*), by Robert Potonié. Gebrüder Borntraeger, Schöneberger Ufer 12 a, Berlin W. 35, 1928. 173 pp., 27 figs. Price, 12 M.

Kohlenpetrographisches Praktikum, by Erich Stach. Gebrüder Borntraeger, Berlin, 1928. 196 pp., 64 figs. Price, 10.80 M.

MISSISSIPPI

"Paleozoic Rocks of Mississippi", by William Clifford Morse. *The Journal of Geology*, Vol. 36, No. 1, January-February, 1928, pp. 31-43. *University of Chicago Press*, Chicago, Illinois. First adequate description of Paleozoic rocks of Mississippi. Mentions petroleum residues in several formations.

OKLAHOMA

The following publications have been issued by the Oklahoma Geological Survey, Norman, Oklahoma:

"Geology of Osage County," by H. T. Beckwith. *Bulletin 40-T*. 62 pp., 4 plates, 17 figs. Price, $0.30.

"Oil and Gas Geology of Payne County," by A. H. Koschman. *Bulletin 40-X*. 13 pp., 1 plate, 4 figs. Price, $0.30.

"Oil and Gas Geology of Harmon, Tillman, Jackson, and Greer Counties," by R. L. Clifton. *Bulletin 40-Y*. 24 pp., 1 plate, 1 fig. Price, $0.30.

"Oklahoma, the Geologists' Laboratory," by Charles N. Gould. *Circular 16*. 16 pp., 7 plates. Price, $0.05.

TEXAS

"Petroleum Engineering in Wortham Oil Field," by H. B. Hill and Chase E. Sutton. *U. S. Bureau of Mines*, Washington, D. C.

WYOMING

"Geology and Oil and Gas Possibilities of the Bell Springs District, Carbon County, Wyoming," by C. E. Dobbin, H. W. Hoots, and C. H. Dane. *U. S. Geological Survey Bulletin 796-D*, Washington, D. C. i-iv, 171-20, i-v pp., 7 illus. Free.

THE ASSOCIATION LIBRARY

Headquarters acknowledges accessions:

TRINIDAD

From H. G. Kugler:

"Das Eozänprofil von Soldado Rock bei Trinidad"

"Insect remains from Oil Sand in Trinidad," by K. G. Blair

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The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualification of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

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Memorial

JOHN WALTER McKIM

John Walter McKim was born in Cleveland, Ohio, August 3, 1877. After completing his high school studies, he entered Case School of Applied Science in 1896 and was graduated therefrom in 1900 with the degree of bachelor of science, having majored in mining engineering and geology.

He was connected with the engineering corps of the Pennsylvania Railroad during 1901 and 1902. During parts of 1902 and 1903 he was mining engineer with the Consolidated Mercur Gold Mining Company. From 1903 to 1914, he was consulting mining engineer, with offices in Salt Lake City, Utah. During 1914 and 1915, he was with the Central Mining and Investment Company in South Africa, in charge of smelting work. In 1916, he served as superintendent of the Midvale Minerals Company.

In 1917, he became interested in the petroleum industry. About this time he came to Wyoming and located in Casper. He with his associates organized the Cow Gulch Oil Company and the McKim Oil Company, of which companies he became president and in which he was largely interested at the time of his death. These companies were active in the early exploration work in some parts of eastern Wyoming and particularly the Cow Gulch or Old Woman structure northeast of Lusk, Wyoming. His companies were interested also in certain parts of the Cat Creek field, Montana.

During the past several years, he maintained an office in the First National Bank Building, Denver, Colorado, and made his home at the Denver Athletic Club in that city.

He was interested always in the development of the West and attended many of the meetings of the scientific societies of which he was a member. He was a regular attendant at meetings of the Rocky Mountain Association of Petroleum Geologists, taking active part in its deliberations.

In addition to belonging to the American Association of Petroleum Geologists since March 29, 1923, he was a member also of the American Association of Mining and Metallurgical Engineers, American Association of Engineers, American Petroleum Institute, and American Mining Congress. He was a Mason and a member of the Zeta Psi Fraternity.

Mr. McKim was unmarried and is survived by his father, John Blair McKim of Fort Wayne, Indiana, and by two sisters, Esther Romaine McKim and Emma B. McKim of San Diego, California.

A short time previous to his death he had become interested in the work which the Colorado School of Mines and its graduates were accomplishing, and developed a friendly feeling for that institution. As a consequence, his heirs saw fit to give expression to his desire to help this work on by donating to the Colorado School of Mines the major portion of his splendid engineering

and technical library. Such kindness and generosity met with great appreciation by the recipients and all those familiar with Mr. McKim's wish to be of assistance to that institution.

His sudden death occurring in Denver, December 31, 1927, was a shock to his friends and acquaintances.

CHARLES T. LUPTON

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

DONALD C. BARTON, consulting geologist and geophysicist, Petroleum Building, Houston, Texas, delivered a two-weeks' course of lectures in March at the University of Chicago. Dr. Barton is the author of technical publication No. 50 of the A. I. M. E., entitled "The Eötvös Torsion-Balance Method of Mapping Geologic Structure."

WALTER KAUENHOWEN, petroleum geologist and geophysicist, arrived in the United States last February. Dr. Kauenhowen is the author of a recent publication by Julius Springer of Berlin, entitled "Die Verwässerung von Erdölfeldern, ihre Ursachen und Bekämfung" (The Flooding of Oil Fields, its Causes and Control).

R. S. KNAPPEN has been transferred from the general office of the Gulf Oil Companies at Pittsburgh to the headquarters of the Gypsy Oil Company, a subsidiary of the Gulf, at Tulsa, Oklahoma.

CHASE PALMER, a chemist internationally known among petroleum engineers and geologists for his studies of oil-field waters and for his widely used system of interpreting water analyses, died at his home in San Francisco, November 18, 1927.

J. WALLACE BOSTICK is now in his new home at 4648 Waneta Drive, Dallas, Texas.

DAVID WILLIAM BRUNTON, mining engineer and industrial organizer, aged 79 years, died early in January, 1928, at Denver, Colorado. Dr. Brunton took an active interest in the science of geology. Of his twenty useful inventions, the best known is the Brunton compass.

The Ardmore Geological Society, of Ardmore, Oklahoma, has elected officers for 1928 as follows: president, CHARLES E. CLOWE; vice-president, A. M. MEYERS; secretary-treasurer, GEORGE E. BURTON. The program committee, consisting of GEORGE E. BURTON, C. W. WHEELER, and SAM WOODS, has arranged for a series of papers on oil-field problems.

New officers of the Fort Worth Geological Society are: president, B. E. THOMPSON; vice-president, FORD BRADISH; secretary-treasurer, C. E. YAGER.

LOUIS C. CHAPPUIS, formerly assistant chief geologist for the Richfield Oil Company, is now employed by the firm of A. E. Starke, consulting geologist, in Los Angeles, California.

DILWORTH S. HAGER has resigned as chief geologist of the Vacuum Oil Company at Houston, Texas, and will open an independent office for work in that state.

FREDERICK G. CLAPP is making a study of the oil resources of the five northern provinces of Persia for the Persian government. This is the first comprehensive study of these oil reserves.

GEORGE OTIS SMITH, director of the U. S. Geological Survey, is the newly elected president of the American Institute of Mining and Metallurgical Engineers, succeeding E. DEGOLYER.

New officers of the petroleum division of the A. I. M. E. are: A. W. AMBROSE, chairman; C. R. MCCOLLOM, associate chairman; E. O. BENNETT, vice-chairman for production engineering; JOSEPH JENSEN, vice-chairman for production; ARTHUR KNAPP, vice-chairman for economics; LESTER C. UREN, vice-chairman for research engineering; H. W. CAMP, vice-chairman for refinery engineering.

GLADYS HAWLEY and CHARLES BASSETT were married on February 26, 1928, and have gone to Maracaibo, Venezuela, where Mr. Bassett is employed by the Lago Petroleum Corporation. Mrs. Hawley was formerly in the geological department of the Silurian Oil Company, Tulsa, Oklahoma.

E. L. JONES, Jr., who was district geologist for Roxana and Comar Oil companies in the Ponca City district for the past six years, was transferred on February 15 to the San Angelo district as district geologist for Roxana.

FRED B. ELY has returned from a stay of three months in Venezuela where he was examining oil properties.

D. S. HAGER, formerly chief geologist for the Vacuum Oil Company, has resigned from that organization effective March 1, and will engage in consulting work. R. F. RYAN, formerly located in west Texas with the Vacuum Oil Company, has been transferred to the Houston office.

WILLIAM J. MILLARD, recently with the Trinidad Oil Fields, Inc., made a trip to Venezuela in March. Mr. Millard's address is Room 801, Whitehall Building, 17 Battery Place, New York City.

MR. and MRS. J. WALLACE BOSTICK of 4648 Waneta Drive, Dallas, Texas, announce the birth of a daughter on December 16, 1927.

F. C. MERRITT, vice-president of the Elliott Core Drilling Company of Los Angeles, returned on March 12 from an extended trip through Texas.

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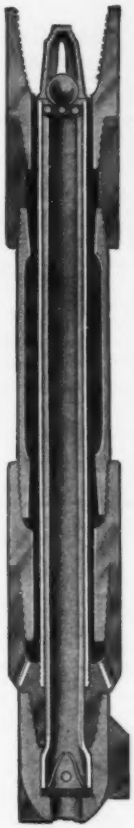

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